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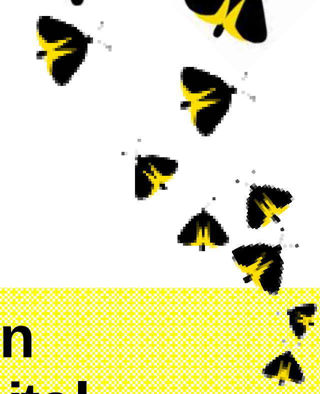
Threatened Species Network
University of Canberra, Canberra

It's all right to have butterflies in your stomach. Just get them to fly in formation.
Dr. Rob Gilbert



Community Monitoring of Golden Sun Moths in the Australian Capital Territory Region, 2008-2009

Funded by the Threatened Species Network, a community-based program of the Australian Government and WWF-Australia

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Canberra, November 2009

UNIVERSITY OF CANBERRA

Threatened Species Network

WWF Australian Government

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Project summary

Starting in October 2008, members of the Institute for Applied Ecology at the University of Canberra and the community group, Friends of Grasslands (FOG) successfully ran a pilot program to monitor the endangered Golden Sun Moth (*Synemon plana*) (GSM) in natural temperate and exotic grasslands in the ACT region (including nearby sites in NSW). The pilot study:

- developed, tested and reviewed procedures suitable for use by community groups for the purpose of counting flying moths and moth pupal cases and recording habitat, including vegetation and habitat quality;
- recruited and trained volunteers from the community who used the procedures to survey and collect baseline data from 28 sites across the ACT and surrounding region;
- analysed the data and summarised the results, so providing a basis for making recommendations to the managers of the grasslands surveyed; and
- raised public awareness of the GSM and natural temperate grassland conservation by involving members of the community in the survey and through presentations, posters, media releases and a web page devoted to the project.

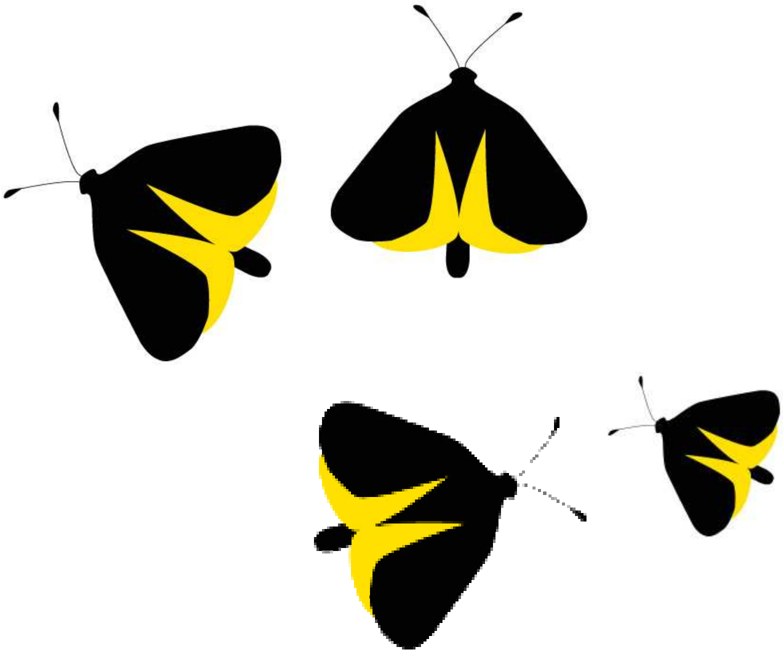
The main findings relating to the conduct of this study were that:

- recording the presence and absence of GSM is an appropriate aim for community monitoring;
- GSM adults and pupal cases can be reliably identified by the public after training and with supervision by experts;
- vegetation surveys require expert supervision and advice and cannot be achieved by community volunteers working alone;

- the greatest challenge for volunteers appeared to be matching the time they are available to conduct the surveys to the times at which the moths are flying; and
- there is widespread support by government, universities, land managers and the community for ongoing GSM monitoring. Currently, Friends of Grasslands is working with key stakeholders to develop an ongoing monitoring program.

Highlights drawn from the data relating to the moth's distribution, abundance and biology include the following points:

- Male and female moths were active until mid January 2009 which is later than expected on the basis of observations in past years and by other observers.
- GSM were found at 20 (71%) of the 28 locations surveyed. At half of the locations, they were present in low-moderate numbers. They were in high-very high abundance at six sites and absent from eight locations. Casual observations in a further six locations revealed that moths also occurred there.
- Two of the most abundant populations recorded were present at grasslands dominated by the exotic Chilean needle grass.
- GSM populations were discovered at some sites where they had not been recorded before, and conversely were absent from previously occupied sites.
- Examination of the pupal cases collected showed the sex ratio to be 60% male to 40% female, when it had been expected to be 50:50.
- A number of threats (e.g. weed invasion and lack of biomass reduction) to GSM habitats were identified and informed the recommendations suggested for the future management of individual grassland sites.



The most beautiful thing we can experience is the mysterious. It is the source of all true art and science.

Albert Einstein

Introduction

- The Golden Sun Moth – A flagship species in natural temperate grassland
- Community involvement in monitoring projects
- Project aims and objectives

Introduction

The Golden Sun Moth - A flagship species in natural temperate grassland

The endangered Golden Sun Moth (GSM) (*Synemon plana*, Castniidae) is a small diurnal moth that is one of the few Australian listed endangered insect species in south-eastern Australia (ACT Government 2005). *S. plana* is one of the most iconic moth species in natural temperate grasslands in south-eastern Australia. It is currently nationally listed as critically endangered under the *Environment Protection and Biodiversity Conservation Act 1999*, and listed as critically endangered in New South Wales (NSW), Victoria and the Australian Capital Territory (ACT). The moth's original habitat, the natural temperate grassland in south-eastern Australia, has been reduced to less than 0.3% of its former extent due urban and agricultural development (Kirkpatrick, McDougall et al. 1995). The remaining natural temperate grassland is threatened by habitat loss, fragmentation and alteration. Consequently, natural temperate grassland is an endangered ecological community and species that inhabit it are at great risk of becoming extinct. The moth's conservation status has been acknowledged recently by WWF Australia which listed the GSM as one of the ten 'battlers of Australia'.

Community involvement in monitoring projects

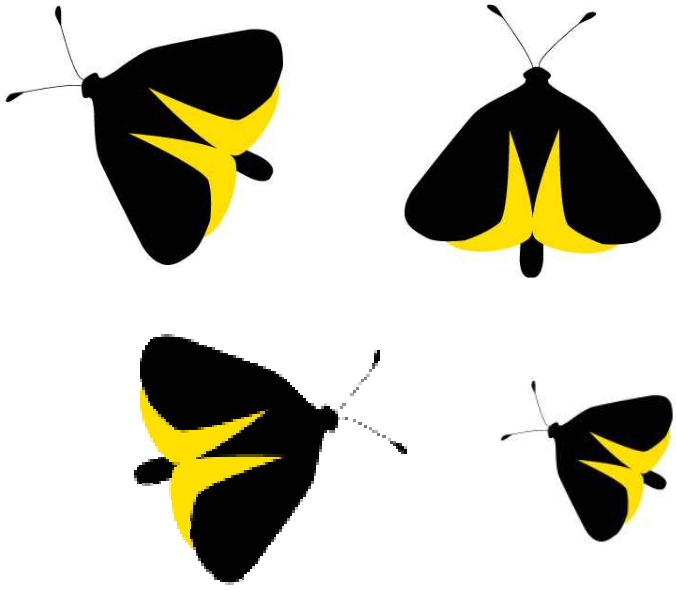
Many conservation objectives can only be achieved with the help of a broader community. Information that is obtained on species, populations, communities and ecosystems from members of the community can have a wide application in interpreting trends, abundances and distribution patterns. The findings derived from volunteers' observations in conservation biology are particularly useful for elucidating necessary management actions and for recording the effectiveness of applied management strategies. However, to obtain results that are reliable, methods need to be standardised and evaluated. In addition, field training sessions that include demonstrations of the proposed methods, combined with workshops on the theoretical background, are essential for successful monitoring studies (New 2006). Collaborations between community groups and research institutions can be of great value in monitoring programs. Therefore, the coordinators of the 'Sun Moth Count' project, the Institute for Applied Ecology at the University of Canberra and Friends of Grasslands, collaborated with the members of a variety of other community groups within the ACT and NSW (e.g. Ginninderra Creek Catchment Group, Field Naturalists' Association of Canberra), with government agencies, and associates from other research institutions such as CSIRO Entomology. All volunteer participants in the Sun Moth Count were active in natural temperate grassland conservation and had a keen interest in understanding and protecting Australia's threatened insect biodiversity.

Project aims and objectives

The overall aim of this pilot study was to develop and evaluate standardised monitoring protocols for use by community groups and to trial the approach with volunteers recruited by Friends of Grasslands from their own and various other groups. The study also set out to establish a basic information guide for future GSM monitoring that could provide information on the moths as well as helping to provide guidelines for site management.

The specific objectives were:

1. to review current knowledge on the distribution and abundance of GSM populations in the ACT region and to set the current distribution into a national context;
2. to determine the most suitable and cost effective method(s) that community volunteers can use to (a) detect the presence of GSM and (b) to estimate the abundance of known GSM populations at discrete sites;
3. to floristically survey GSM habitat and assess its condition;
4. to identify current and potential threats to GSM and natural temperate grassland at monitoring sites;
5. to actively involve a variety of community groups;
6. to foster long term awareness of GSM and its conservation status, in the broader context of natural temperate grassland among the general public; and
7. to evaluate the effectiveness of the GSM monitoring program as a community capacity building program.



A Symbol of Hope

A butterfly lights beside us like a sunbeam

And for a brief moment its glory and beauty belong to our world

But then it flies again

And though we wish it could have stayed...

We feel lucky to have seen it.

Unknown

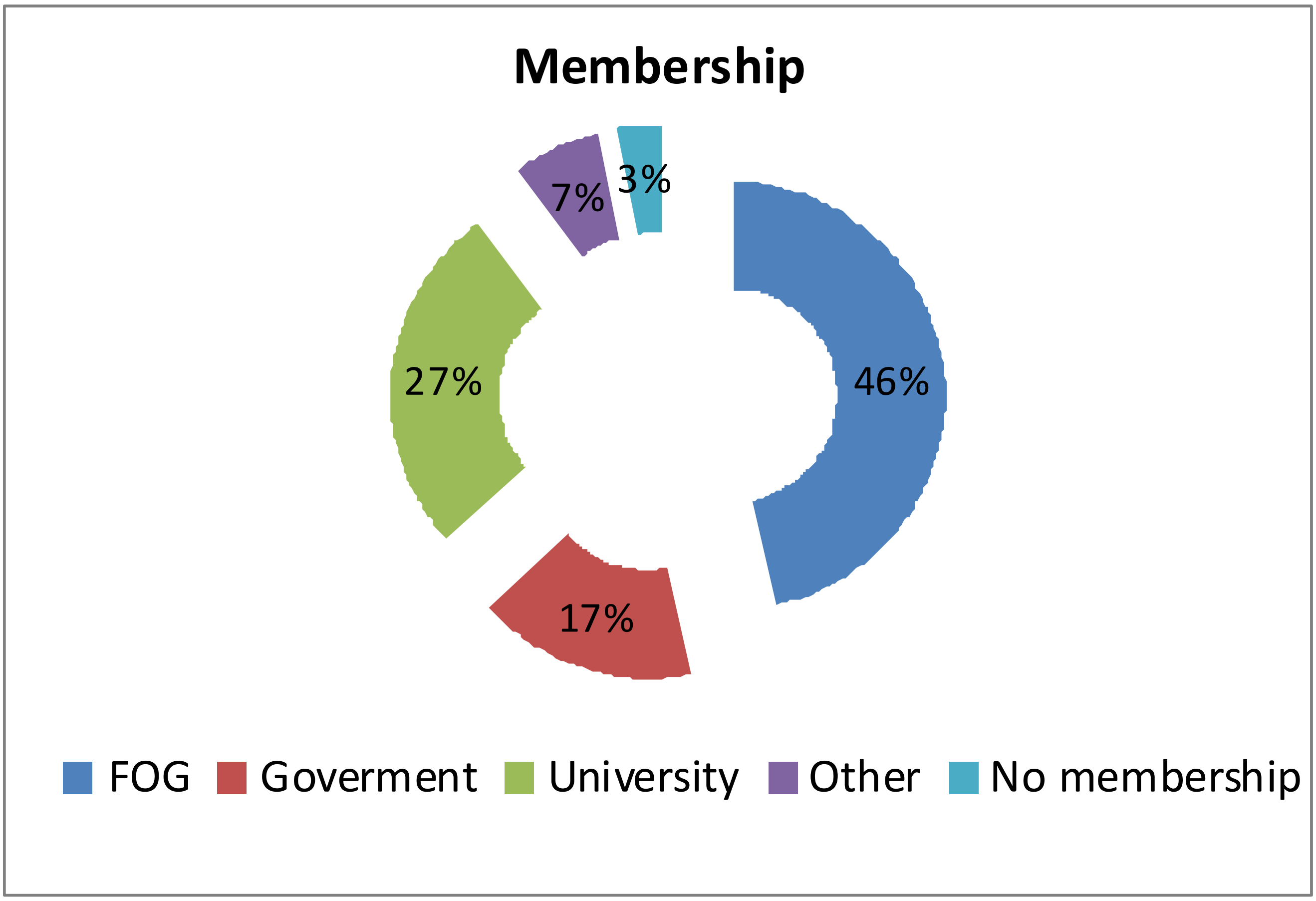
Community involvement and capacity building

Community involvement and capacity building

Participant demography and feedback

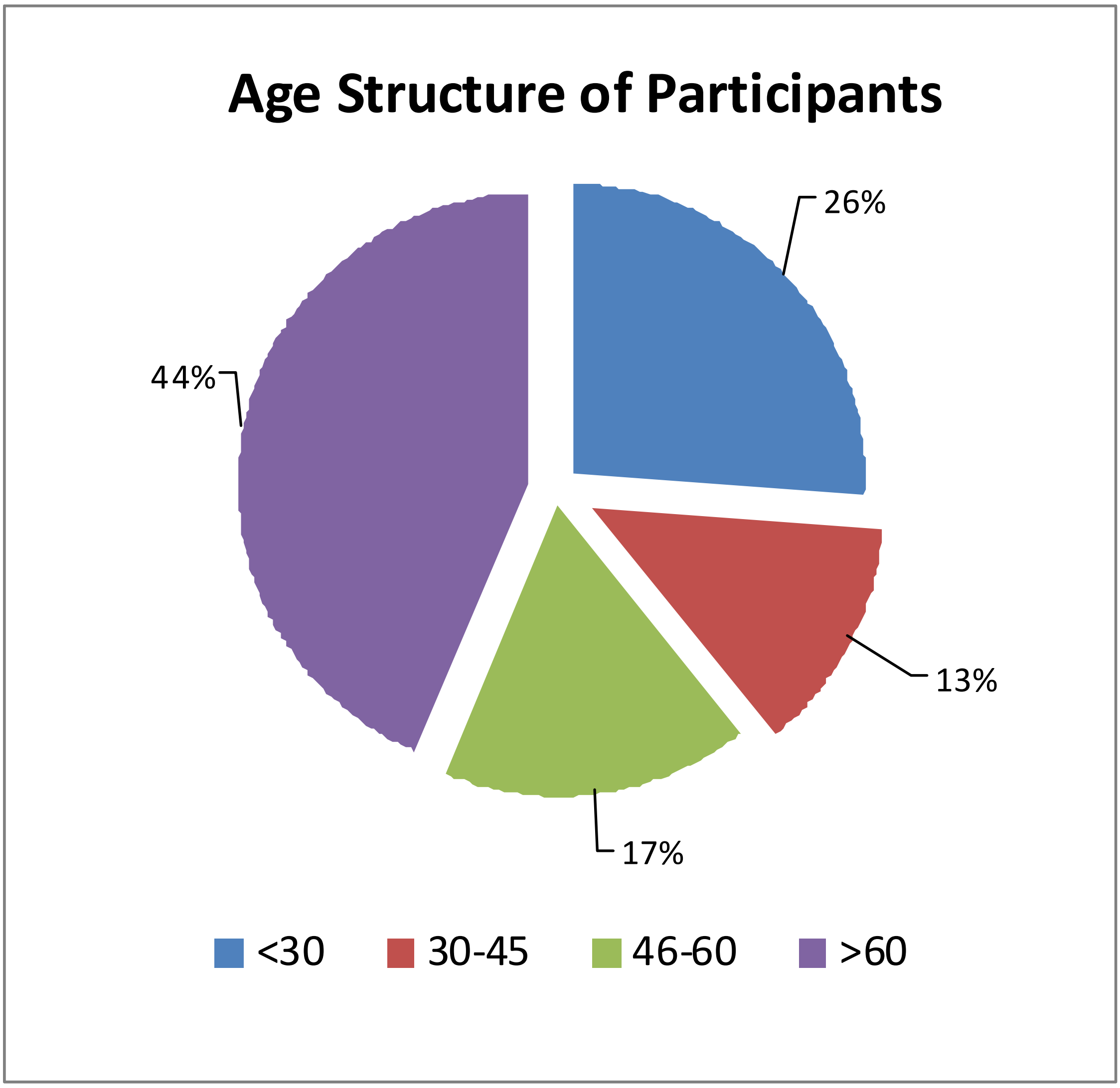
Data were gathered and analysed in a pilot, volunteer-based GSM monitoring project between September 2008 and April 2009 in the ACT and surrounding region. A total of 37 volunteers (48% males, 52% females) were actively involved in the project. More than 50 members of the community from the ACT and NSW took part in workshops, training sessions and the on-ground monitoring program. Many of them belonged to a variety of organisations and institutions such as Friends of Grasslands, the University of Canberra, the Institute for Applied Ecology at the University of Canberra, Field Naturalists Association of Canberra, Ginninderra Catchment Group, and government agencies (Figure 1).

Figure 1: Breakdown of volunteer affiliation (Friends of Grasslands - FOG), government agencies (e.g. Department for Environment, Water, Heritage and the Arts, ACT Parks, Conservation and Lands), universities (e.g. University of Canberra) and others (ornithologists, Frogwatch).



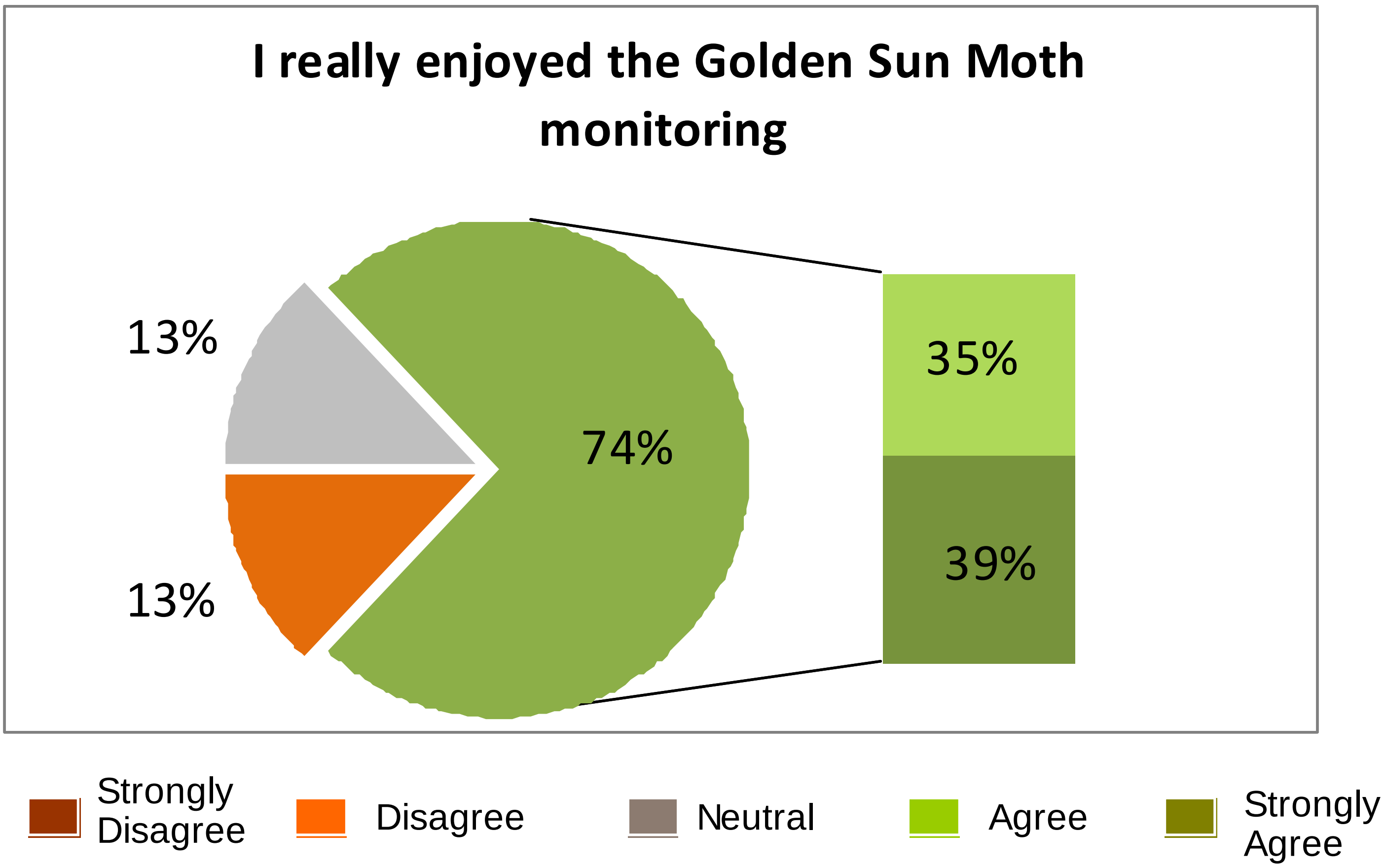
Questionnaires were sent out to all participants at the close of the project. From the 24 responses received, we are able to show that the age structure of the participants was relatively balanced, probably as a consequence of the involvement of people from a variety of community groups. The majority (44%) of participants were >60 years old, 17% were between 46-60, 13% between 30-45, and a quarter of the participants were aged under 30 (Figure 2).

Figure 2: Pie chart indicating the overall age structure of the Golden Sun Moth project participants.



About 30% of all participants had not heard of the GSM prior to our project and the overall majority (74%) really enjoyed their involvement in the project (Figure 3).

Figure 3: Volunteer ratings of their enjoyment of Golden Sun Moth monitoring.



At the beginning of the project, four workshops of more than six hours each and three field training sessions were held to introduce the participants to the program, to moth identification and to the monitoring methodology. Copies of presentations and other materials mentioned in this report are available from Friends of Grasslands. On site assistance to volunteers when monitoring was underway was available throughout the complete project. A coordinating group of two volunteers and a project coordinator allowed comprehensive communication between them and participants and a weekly update on the progress of the project. During the project, six online newsletters were produced and sent to all participants. In addition to the coordinating group, two full time volunteers visiting from Germany assisted with preparations for the workshop, field work and the preparation of the GSM web page and poster material. Each participant received a ‘letter of appreciation’ at the final workshop.

According to the information provided by participants, they contributed more than 500 volunteering hours during the project. In addition, a total of 480 hours were required for organisation, field assistance, analysis, report writing and other matters.

Publicity

One major aim of the project was to foster long-term awareness in the general public of the endangered GSM and its conservation status, in particular in the broader context of natural temperate grassland conservation. In order to promote the project, to recruit participants, and to sensitise a broader public about GSM and natural temperate grassland conservation, we created and launched a web page (http://aerg.canberra.edu.au/teams/osborne/moth-count/?page_id=22) that gained wide popularity due to its informative character and well-structured design. `

The web page contains information about the biology and ecology of the GSM, information about the project including guidelines, contact details and joint collaborators (WWF Australia, Friends of Grasslands and Institute for Applied Ecology at the University of Canberra). In addition, the web page was used to announce 'News and Events' and to provide access to the published GSM Newsletters.

Two posters were prepared as part of this project to inform a wider public and to encourage them to become involved in future monitoring activities. One poster was shown at the ‘Snakes Alive’ exhibition at the Australian National Botanic Gardens in Canberra from 15-21 January 2009. More than 4,000 people attended the exhibition and many expressed great interest in the poster. The second poster illustrates the species characteristics and highlights the potential habitats where the moths can be seen by the public. It provides an overview of the main flight activities of the moths and details of whom to contact in the case of future sightings. The poster is designed to be distributed to schools, community groups and public places prior to the next round of community monitoring.

Three press releases (one prepared by WWF Australia and two by Anett Richter and Geoff Robertson) increased public awareness about the threats to the GSM and the vulnerability of natural temperate grassland. An article (see page 17) appeared in the Sydney Sunday Herald reporting that WWF had nominated the GSM as one of the ten Aussie battlers, species that are at great risk of extinction and require urgent help to survive. One research result from the project that attracted much media interest was the finding that the moths have a biased sex ratio. The ‘story’ was published in the Morning Bulletin, the Daily Telegraph, the Daily Liberal, AAP Newswire and the Sunday (Canberra) Times (see page 18).

Regular updates on the project’s progress and summaries of presentations were published in the Friends of Grasslands Newsletter.

Article from the Sydney Sun Herald, around 23 January 2009. We understand the same article was in the Melbourne Herald Sun on 23 January.

At the end of the line

Megan McNaught
environment reporter

THE World Wildlife Fund is commemorating Australia Day with an honours list of its own.

It has nominated 10 "Aussie Battlers" — endangered species which it says need urgent help to survive.

WWF Threatened Species Program Manager Kat Miller said 346 animal and 1249 plant species were now listed as threatened under federal law.

"Australia has the worst record of mammal extinction in the world," Ms Miller said.

WWF's top 10 Aussie Battlers are:

1. GREEN and gold frog — one of Australia's largest frogs, its home has been decimated by drought.

2. CASSOWARY — being large and flightless means road kills are one of the major causes of adult cassowary deaths.

3. GREEN sawfish — evolved from ancient sharks with a unique jaw lined with teeth made from modified scales.

4. YELLOW-FOOTED rock wallaby — the golden fur of this rock wallaby was more likely to be seen on a London street than in outback Australia.

5. RED-TAILED black cockatoo — their nesting hollows are scarce and these endangered birds are left out in the cold.

6. YELLOW-SNOUTED gecko — living in Kakadu National Park doesn't protect from fire and weeds.

7. SWIFT parrot — this parrot has a habit of not looking where it's flying and many are killed due to collisions with cars and home windows.

8. GOLDEN sun moth — this threatened insect has a very short lifespan, living just a few days as an adult.

9. WOOLLY wattle — closely related to Australia's national flower, the golden wattle, and is seen only in a small patch in southwest Australia.

10. BRIDLED nailtail wallaby — named for its horn shaped "nail" at the tip of the tail, this wallaby was once common through eastern Australia. It was believed to be extinct before being rediscovered in 1973 in Queensland.

Article from the Sunday (Canberra) Times, 13 March 2009 by Kate Leigh.

Moth's a puzzling case

HOW THE golden sun moth survives is an astonishing feat.

The critically endangered moth lives for just two or three days after breaking free of its cocoon. In its small window of existence, the purpose of the moth is to mate and keep the population alive. The moth has no mouth or gut and it will eventually die of starvation. Rather than waste time feeding, it lays as many eggs as possible.

Now a University of Canberra entomologist has uncovered a phenomenon that casts doubt on the future of the golden sun moth.

Anett Richter, with the help of 40 Friends of Grasslands volunteers across Canberra, has discovered there are more male moths than females.

"Based on our analysis, it's estimated that the sex ratio is 60 per cent males to 40 per cent females," Ms Richter said.

"In theory it should be approximately one to one ... We don't know why at the moment."

Male moths are relatively easy to identify during flight. Their wings are dull brown compared with the bright orange underwings of the female moths.

But pupal cases can reflect a much more accurate number of males and females as the environment does not have the same influence on them.

Unlike the female pupal cases, the male ones have two tiny bumps at the base, discernible only under a microscope. Ms Richter examined more than 500 pupal cases.

The moth larvae can live for up to two years in the soil before cocooning themselves in these pupal casings.

Ms Richter said temperature changes, pressure for food or high predation rate in the soil might influence the moth's sex ratio.

The golden sun moth is found in various sites across Canberra, including York Park in State Circle and the native grasslands at Majura. The moth was once common and widespread throughout south-east Australia, but it has become one of Australia's most endangered insects.

This year, WWF Australia listed the moth in its top 10 Aussie battlers list of endangered species that needed urgent funds to survive.

"This little moth has a great personality," Ms Richter said.

"I have always wondered how the moths can survive in this climatically extreme ecosystem."

Moths fly during the hottest part of the day between late October and mid-January.

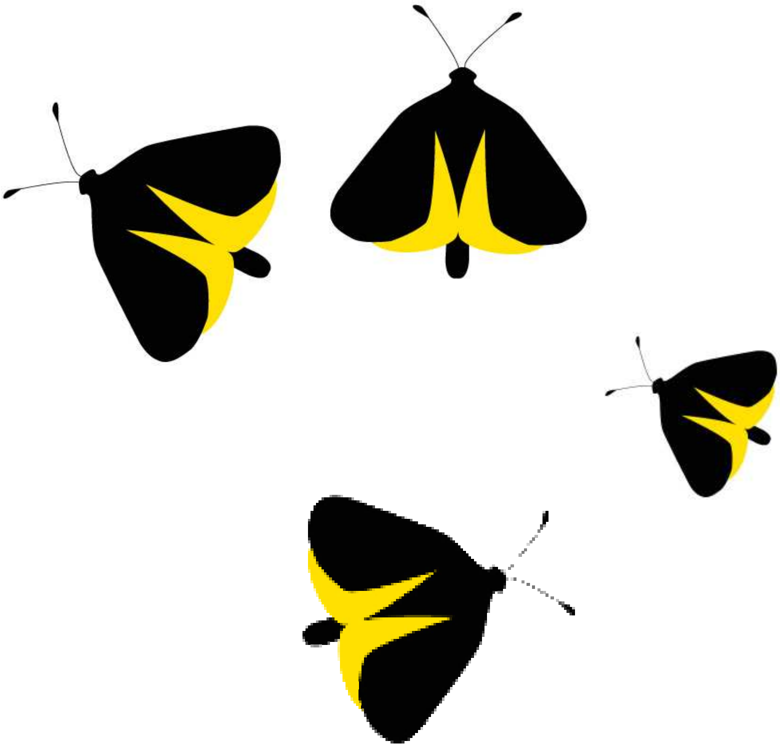
Ms Richter said she had worked in the moths' native temperate grassland habitats during their flying time and it could become extremely hot.

"The moths don't mind it – they need the high temperatures," she said.

"If you look at the dry hard soil and the pupal cases, then you wonder how a little moth can emerge out of this soil that must feel like a rock. The moths can do it easily."

She said more research was needed to shed more light on the moths' biology and ecology to secure their survival.

"This little moth has a great personality," says Anett Richter. Photo: KATE LEITH



For a community to be whole and healthy, it must be based on people's love and concern for each other.
Millard Fuller

Project methodology

- The Golden Sun Moth monitoring scheme
- Counting moths and pupal cases
- Vegetation survey and habitat quality assessment

Project methodology

The Golden Sun Moth monitoring scheme

We encouraged each participant to become a monitoring coordinator for a grassland site that was either provided by the project coordinators or selected by the participants themselves.

For each monitoring site we provided a digital map with the location of 12 randomly selected 1m^2 survey plots. Each plot was surveyed four times before the survey was considered to be finished.

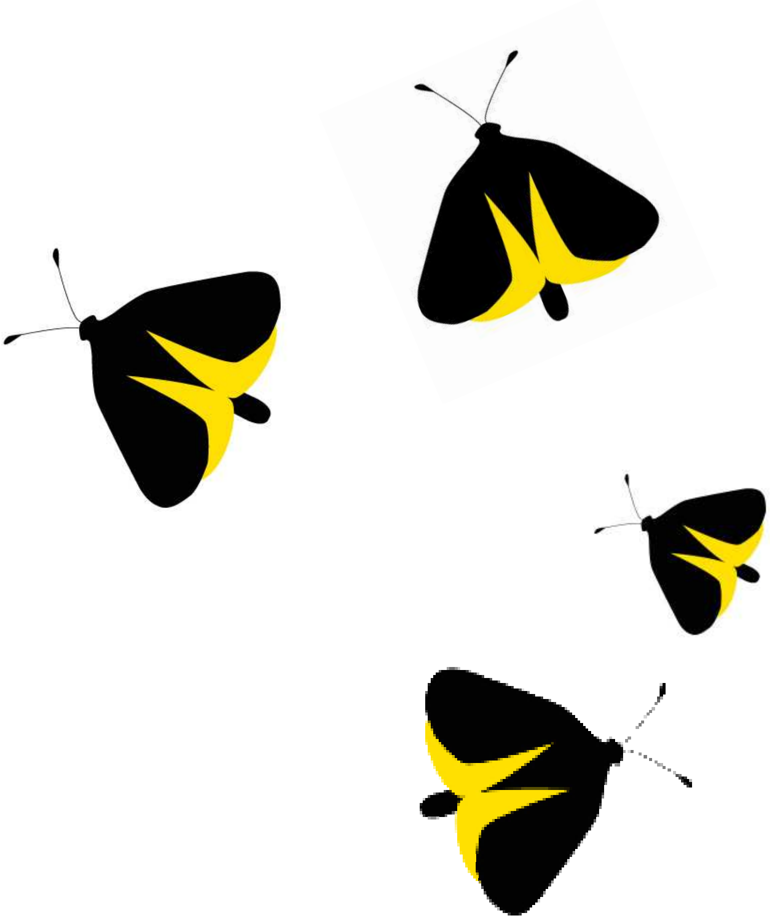
Counting moths and pupal cases

We asked participants to count empty GSM pupal cases in the 12 survey plots and to record their exact location within the plot. Participants then collected the cases in specimen jars for later measurement and sex determination. At the same time, circular plot counts of flying adult moths were made over 30 seconds within a radius of 15 metres of each 1m^2 plot. All information obtained in the field was recorded on the data sheets provided.

Vegetation survey and habitat quality assessment

As the presence of native grass species such as wallaby (*Austrodanthonia* spp.) and spear (*Austrostipa* spp.) grasses are assumed to be the main food source for GSM larvae, we encouraged participants to record floristic data at all 12 plots. The data recorded included a list of grass and forb species present, the percentage of the plot that comprised bare ground, and the abundance and basal cover of dominant plant species.

In order to evaluate the current conservation status and quality of natural temperate grasslands that are considered as the main habitat for GSM, a habitat quality assessment recording sheet was provided. The form included questions about current biomass reduction, weed invasion, indicators of intense grazing activity, and other observations made at the time of the surveys.



Project results

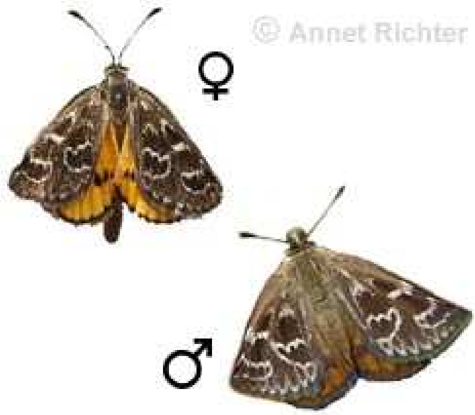
- Current distribution of the Golden Sun Moth
- Insight into the sex ratio of the Golden Sun Moth
- Identification of current threats to the Golden Sun Moth
- Management recommendations

Project results

Current distribution of the Golden Sun Moth

Prior to European settlement it is assumed that the GSM was widespread in south-eastern Australia in natural temperate grassland. This native grassland had an extensive although patchy distribution in the region. Based on historical records it is known that the GSM was found as far north as Winburndale near Bathurst and the Yass Plains in New South Wales. The GSM also inhabited large areas of central Victoria from Bright in the east to Nhill in the west, through to Bordertown in South Australia, and large areas of the ACT.

The transformation of native temperate grassland into urban and agricultural land has caused more than 95% of the former habitat of the moths to disappear or became highly degraded. As a result of the significant alteration of the moths' habitat and the loss of native grasses on which the species is dependent, the GSM has undergone an extensive reduction in its area of occupancy. This reduction has been accompanied by population decline and local extinctions.



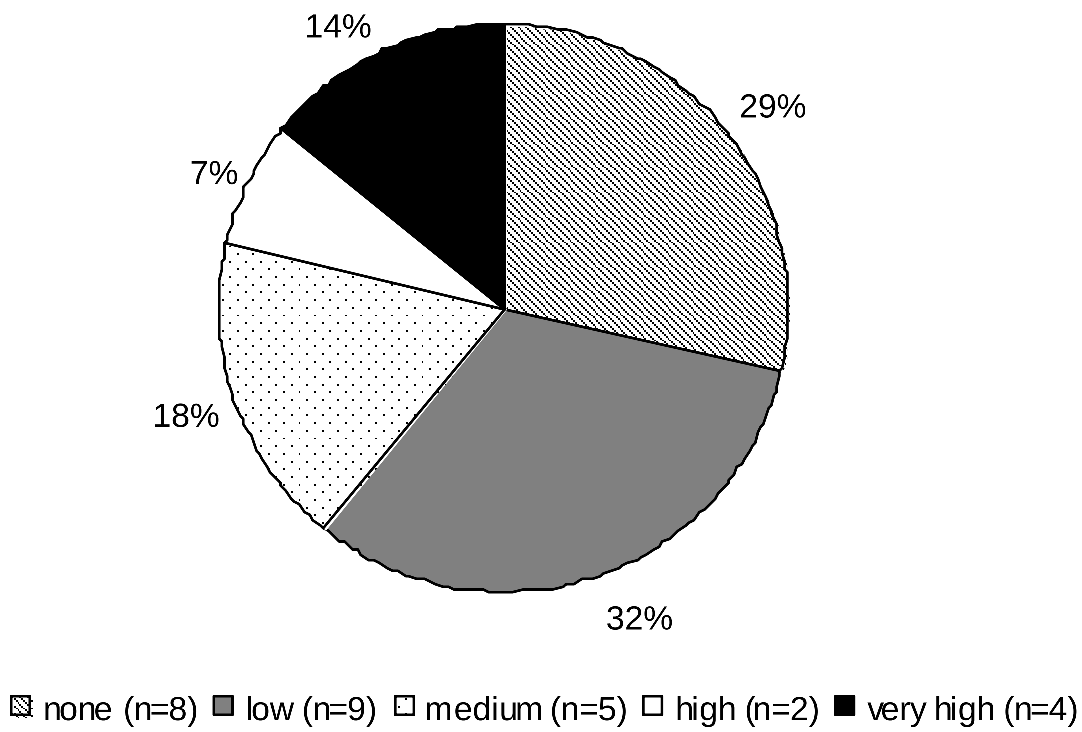
Today, the GSM is restricted to small, often highly fragmented, native grassland remnants. These remnants are threatened by ongoing habitat disturbance, destruction from urban and industrial development, and weed invasion.

The recognition of the species as highly threatened has resulted in an increase in research and survey activity directed at obtaining new information on its distribution. For example, in 1994, *S. plana* was known from only 10 sites in the ACT, five sites in Victoria and one site in NSW. However, surveys in subsequent years have discovered more sites with the species throughout its historic range. Currently, we know that the GSM is present at approximately 30 locations in the ACT, 45 in Victoria and 48 in NSW. It is not entirely clear if this increase in GSM populations is a reflection of increasing survey effort or a general population increase. It does however demonstrate the importance of undertaking active surveys and monitoring programs.

Despite this increase in the number of known populations, at most sites the species occurs in low numbers and many of these sites are of no more than a few hectares. This is true for example in Victoria (Gilmore, Koehler et al. 2008), New South Wales (Gibson and New 2007) and the ACT (Edwards 1994; ACT Government 2005).

During our GSM monitoring project, 28 locations were surveyed by the participants. The summation of moth sightings during site visit was used to provide an estimate of the relative abundance of GSM at these 28 sites. This allowed us to compare GSM populations across these locations. The highest number of counted individuals was used to categorise each population into: (a) small populations (low numbers of individuals = 1-20), (b) medium-sized populations (medium numbers of individuals = 21-50), (c) large populations (high numbers of individuals = 51-100) or very large populations (very high numbers of individuals = several hundreds). The main finding from these counts was that GSM were found at 71% of the sites surveyed. At half the locations populations were characterised by low or medium numbers of individuals. The species was present as small populations at nine locations and medium-sized populations at five locations. At only at six locations (21%) were GSM recorded in high or very high abundances and therefore classified as large-very large populations. The species was not found at eight locations (29%) (Figure 4).

Figure 4. Golden Sun Moth site occupancy and relative abundance



One important finding was the discovery of new GSM populations and the confirmation of the absence of *S. plana* at previously occupied sites. A list of total sightings with a description of the locations is provided in Table 2 of this report (see page 35). GSM were also observed during informal visits to grasslands that were not monitored. Several medium to large GSM populations were found over a large area in north-west Yarralumla, south of Lake Burley Griffin and along the Molonglo River (see Table 2, footnote 7). Flying GSM adults were also seen at Goorooyaroo, Throsby, and St John's, Reid, locations which are listed in the shaded cells in Table 2. In addition, a few moths were observed at sites where no moths were counted in the monitoring plots; they were seen whilst observers walked towards the plots and disturbed them. These sightings include the locations of Gundaroo Common and Lawson (ACT). Adding these sites to the 20 identified with moths during the counts, a total of 26 sites were recorded with GSM in the ACT region over the 2008-09 summer.

Insight into the sex ratio of the Golden Sun Moth

In the vast majority of organisms that sexually reproduce, individuals of the two sexes are produced in approximately equal numbers independent of the sex determining system. The system of equal sex ratios is maintained by natural selection processes because selection equalises parental contributions by the two sexes (Fisher 1930)**.** This fundamental principle in sex ratio theory argues that members of the minority sex tend to have higher fitness than members of the majority sex. This tendency has been acknowledged since the beginning of evolutionary theory (Darwin 1859) and has inspired evolutionary biologists ever since.

Previous research has been conducted on the biology and ecology of the GSM. This has included its general biology and distribution in the ACT (Edwards 1991; Edwards 1992; Edwards 1994; Clarke and Dunford 1999), habitat requirements and restoration (O'Dwyer and Attiwill 1999; O'Dwyer and Attiwill 2000), genetic population structure (Clarke and O'Dwyer 2000; Clarke and Whyte 2003) and population dynamics (Gibson and New 2007)**.** However, prior to this study, nothing was known about the sex ratio within the species.

Part of this monitoring project was to contribute to a better understanding of the species biology. A total of 651 pupal cases were collected in 2007 and in 2008 as part of the GSM monitoring project. Because it is possible to determine the sex of the individual moth from morphological characteristics of the pupal case, they were examined by microscope at the laboratory at the University of Canberra, revealing a sex ratio of 60% males to 40% females (A. Richter 2009, in preparation) (Figure 5), but with the notable exception of two sites where more than 60% of individuals were female.

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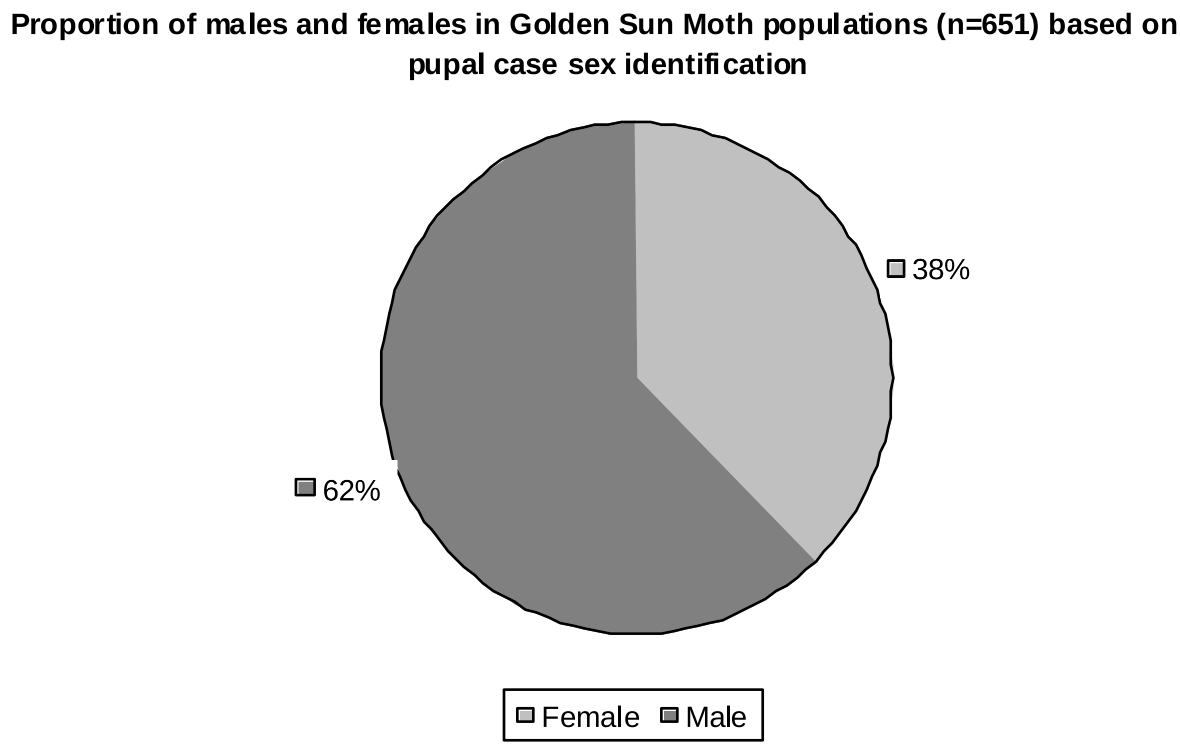
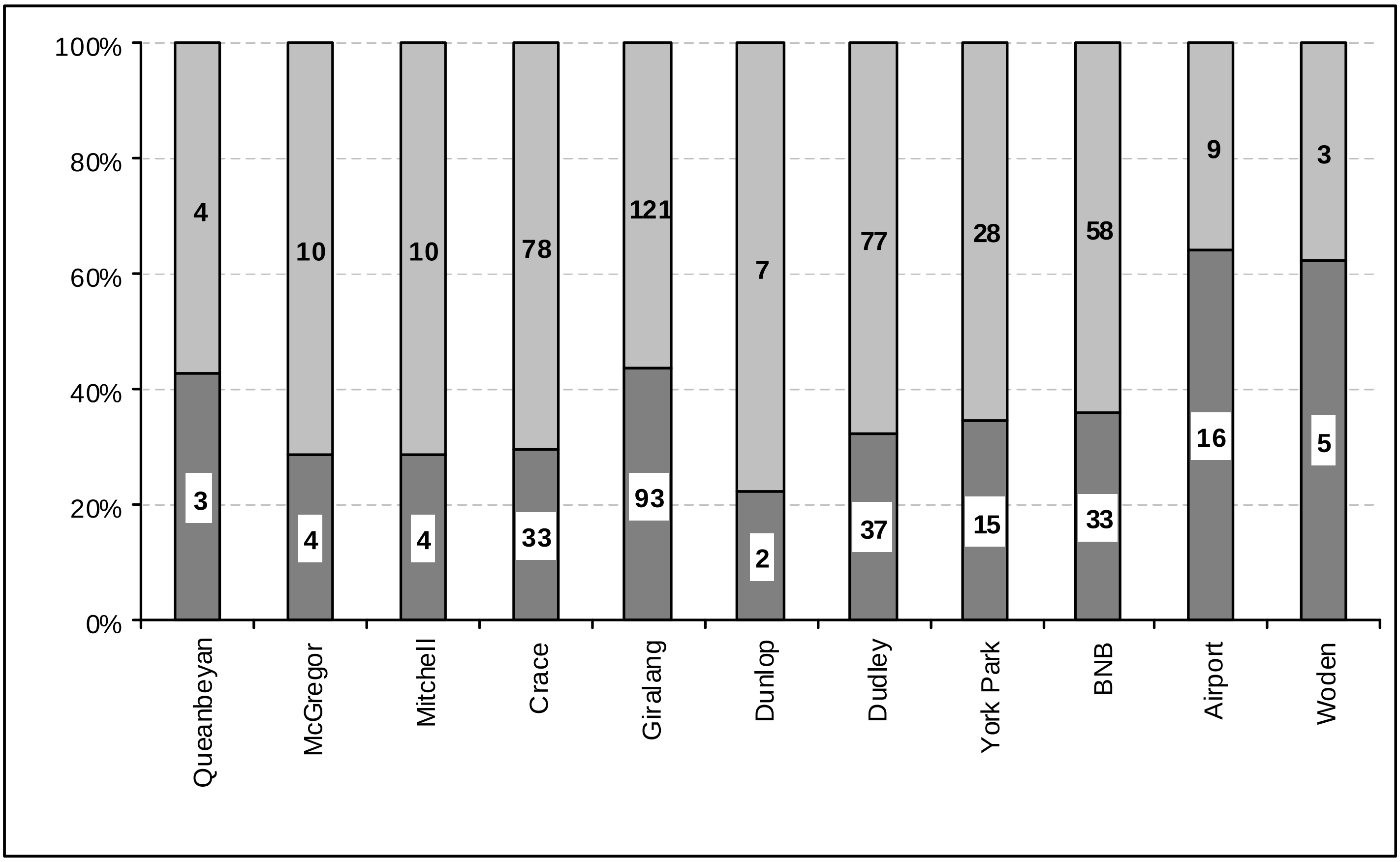
Figure 5. Proportion of males and females in Golden Sun Moth populations



In order to test if this pattern of more males than females in *S. plana* was consistent across different sites, the results for each locality were plotted (Figure 6). A biased sex ratio was detected at all sites but the proportion of 60:40 was not consistent. There was, however, a general under representation of females (A.Richter 2009, in preparation).

Figure 6. Numbers of *S.plana* male (light grey) and female (dark grey) pupal cases identified at 11 sites in the ACT and NSW.



These findings are of considerable interest in evolutionary biology, and in a broader sense such results can be important in conservation programs. From a scientific perspective it is important to unravel the mechanisms of environmental, genetic or demographic interactions that are involved in sex determination. Generally, variability in sex ratios has been reported for many lepidopteran species, ranging from those with male biases, through species with males and females with an almost 1:1 sex ratio, to species that produce only female offspring (Jiggins, Hurst et al. 1998; Adamski 2004). In the debate about this variation it has been argued that the biased sex ratio produced in butterfly species can be maternally inherited (Jiggins, Hurst et al. 1998), might be the result of biased predation as a consequence of sexual dimorphism, or results from microhabitat selection, differences in 'catchability' or lags in emergence times of females relative to males (protandry) (Ehrlich, Launer et al. 1984; Frey and Leong 1993).

In our study we recorded the sex ratio based on pupal cases (Figure 7). This is likely to be a less biased estimator than the sex ratio estimation based on flying adults because pupal cases are not influenced by detecting probabilities and have equal ‘survival’ probabilities under natural conditions. Thus, it is expected that the pupal case sex ratio discovered in GSM populations in the ACT is a robust measurement for the sex ratio within *S. plana*.

Figure 7: Dorsal and ventral view of empty Golden Sun Moth male pupal cases under the microscope.

Future research will be needed to validate these findings over several years and among the wider distributional range of the GSM in NSW and Victoria. In addition, it is essential to investigate the underlying processes of sex determination in *S. plana* in order to better understand this phenomenon.

Identification of current threats to the Golden Sun Moth and natural temperate grasslands

The GSM and its habitat are threatened by ongoing native grassland losses and fragmentation due to urban and agricultural development, grassland degradation (e.g. weed invasion) and inappropriate management. In order to effectively conserve species and their populations, the conservation of the species habitat, based on ecological information about the species' specific habitat requirements, is of high priority. To identify current and potential threats to GSM and natural temperate grassland, participants were asked to record

- level of biomass reduction
- signs of grazing activity
- type of grazers
- rubbish sightings and
- any other miscellaneous observations.

The consequences of historical and ongoing losses to natural temperate grassland and continuing fragmentation of the remaining patches continues to be a major threat to the GSM. The two largest populations found in the ACT region occur in the largest patches of natural temperate grassland (Belconnen Naval Transmitting Base (BEO8) and Jerrabomberra Valley "Wooden" (JEO3). At most other native sites the GSM populations are in low abundance; these sites are characterised by small native grassland relicts or degraded grassland.

Urban and infrastructure development over recent years have changed significantly the surroundings of some GSM habitats and consequently increased their degree of isolation. At some sites, invasion by weeds such as Chilean needle grass (*Nassella neesiana*), saffron thistle (*Carthamus lanatus*) and St. Johns wort (*Hypericum perforatum*) is apparent and reducing the quality of the natural temperate grasslands.

Here, we feel it is important to highlight that our survey found very large GSM populations at four grasslands that are dominated by the exotic Chilean needle grass (*Nassella neesiana*). The presence of the species in this habitat has also been recorded in the past in the ACT (Braby and Dunford 2006) and Victoria (Gilmore, Koehler et al. 2008). Based on the presence of cast pupal cases found protruding from Chilean needle grass tussocks (A. Richter 2006, cited in DEWHA 2009) and findings of larvae in several Chilean needle grass grasslands (Richter et al. 2009, in preparation), it is possible that Chilean needle grass is an important component of the GSM larval diet at these sites.

During this project several volunteers recorded hundreds of flying GSM adults at Dudley Street, Constitution Avenue, outside York Park and at Giralang. All these sites are dominated by Chilean needle grass (*Nassella neesiana*) and are characterised by high levels of disturbance. The very large GSM population (up to 685 individuals) at Dudley Street is highly significant for the ACT. Further research is urgently required to understand the relationship between Chilean needle grass (*Nassella neesiana*). *D*ietary investigations on the species are currently underway (A. Richter, pers. communication). Until more is known about the relationship between GSM and exotic grasses, we suggest a dual approach to managing grasslands with both GSM and Chilean needle grass (*Nassella neesiana*): the maintenance of existing Chilean needle grass grasslands with large or very large GSM populations (e.g. Dudley Street and Constitution Avenue) to ensure the survival of these populations which might act as source populations to disperse into other grasslands, while preventing the spread of Chilean needle grass into other areas.

Grazing by native ungulates has always been an important component in the viability of natural temperate grassland. Most sites that are large enough are grazed by kangaroos; with some sites being grazed so low that bare ground dominates the site. At other sites, soil disturbance and increasing weed invasion have been caused by livestock grazing and rabbit activity.

Nearly all locations that were surveyed as part of this monitoring project were located in an urban-semiurban setting. A certain amount of rubbish was reported to be present at most sites. Whilst the presence of rubbish is more an aesthetic issue than an immediate threat, it gives the impression that the site is unmanaged and of little importance. This was recognised by the project coordinators, and one site where *S. plana* is known to occur was completely cleared of rubbish as part of the national 'Clean Up Australia' activity. Approximately 10 kilos of rubbish were removed by hand at a 16ha site in the northern part of Canberra.

Several sites that were monitored had not had any biomass reduction before our survey. The dense growth of a dominant grass species (e.g. kangaroo grass, *Themeda australis*) is considered a threat to the GSM, as it is known that the moths require bare ground and a variety of native grass species for their survival.

Management recommendations

Based on observation and quantitative information gained during our study, we have formulated conservation goals, objectives and actions that we consider important to improve the conditions for the GSM and its habitat (Table 1). We have also drawn on our data and the best current available scientific knowledge to make recommendations for the management of each site surveyed and their GSM populations (Table 2). These recommendations will be discussed with land managers, community groups and other GSM stakeholders with a view to improving the management of GSM sites, and continuing and building a community-university-government GSM monitoring program.

Table 1. Conservation goals, objectives and actions to improve the conditions for the Golden Sun Moth and its habitat

GOAL	OBJECTIVE	ACTION
Community involvement	Community groups are actively involved in GSM conservation.	Maintain the involvement of community groups in protecting GSMs by: • facilitating coordination that links community activities with stakeholders and government agencies, • encouraging the formation of a national (including NSW and Victoria) GSM Conservation Network based on community involvement, • building on the ACT community program, and • continuing to raise community awareness through public environmental education (including school and university programs).
Information	Ongoing monitoring of the distribution and the conditions of all GSM populations in the ACT region is carried out on an ongoing basis.	Undertake ongoing monitoring to maintain up-to-date information on the presence and absence of GSM populations and the relative abundance of selected key populations
	A database of GSM populations is maintained.	Maintain a database of information about the GSM gained from community surveys to support planning, management and research relating to the GSM.
	Information is included in state and national databases.	Link data about ACT GSM populations to the ACT Lowland Native Grassland Conservation Strategy—Action Plan No. 28 and national databases.
	Ecological information is used to underpin adaptive management for GSM populations.	Increase research that addresses current management, management under climate change, and improved management, e.g. in relation to fire and GSM habitat rehabilitation and restoration.
Threats	Threats to GSM populations are significantly reduced or removed.	Describe and monitor threats to GSM populations (including urban development in adjunct habitats, fragmentation, overgrazing, weed invasion, and lack of management).
	The impact and occurrence of weeds of concern is reduced.	Provide information about the spread of weeds of concern and monitor the response of GSM to control programs.
Management	Ecological conditions of GSM habitat are maintained or improved.	Continue to develop and promote 'best practice' management by: • identifying practicable methods for GSM habitat restoration and regeneration, • monitoring the effectiveness of management actions and experimenting with alternative management strategies, and • linking research with monitoring outcomes to develop and apply 'adaptive management'.

Table 2. Golden Sun Moths in ACT and region grasslands. Unshaded cells provide abundance and threats to GSM at each site surveyed, and management recommendations for those sites. Shaded cells refer to grasslands not surveyed but for which some information is available.

Name of the site by geographical area	***Site code (following the ACT Lowland Native Grassland Conservation Strategy, 2005)***	***Abundance of GSM observed in 2008/09 ****	***Threats to GSM identified in this and previous surveys***	***Recommended immediate action***	***Recommended long-term action***
ACT SITES					
Gungahlin					
Mulanggari Nature Reserve (2 sampling sites)	GUO1	Low (2, 2)	No recent biomass reduction, weed invasion from surrounding area, encroaching urban development	Consider biomass reduction	Control weed invasion
Gungaderra Nature Reserve (2 sampling areas)	GU02	Low (0, 4)	No recent biomass reduction	Currently no immediate action required	
Crace Nature Reserve (2 sampling areas)	GUO3	Medium (13, 30)[1]	Weed invasion and disturbance by cattle grazing under drought conditions	Currently no immediate action required Install information sign about native grassland and GSM	Monitor the extent of weed invasion and weed dispersal by livestock
North Mitchell	GUO4	Medium (28)[2]	Rapid urban development and habitat reduction, increasing fragmentation and isolation	Currently no immediate action required	Increase connectivity and minimise habitat reduction

[1] Both sampling areas visited only once
[2] Total calculated from15 points at 1^{st} - 3^{rd} visits.

Name of the site by geographical area	*Site code (following the ACT Lowland Native Grassland Conservation Strategy, 2005)*	*Abundance of GSM observed in 2008/09 **	*Threats to GSM identified in this and previous surveys*	*Recommended immediate action*	*Recommended long-term action*
Goorooyaroo Reserve	Not listed	Many GSM were observed on a FOG field trip (9 Nov 2008).	Nil at present	Currently no immediate action required	Collect better data on site
Throsby	Not listed	One male GSM was observed here in late Dec 08.[3]	Proposed urban development	Currently no immediate action required	Collect better data on site
Majura Valley					
Canberra International Airport (2 sampling areas)	MAO3	Low (17, 17)	Intensively mowed to maintain very low grass structure, weed invasion and fertiliser supplement	Create mosaic of heterogeneous habitats	Apply weed control programs and monitor the responses of GSM population
Campbell Park (2 sampling areas)	MAO5	Low (3, 9)	Weed invasion, rabbit activities and overgrazing by kangaroos	Weed control (St. Johns wort, Chilean needle grass, serrated tussock) and clear area of rubbish and encroaching wood	Control rabbit and kangaroo activities
Jerrabomberra Valley					
Woden Station/ Jerrabomberra West Reserve (2 sampling areas)	JEO3	High (23, 72)	Weed encroachment (saffron thistle, serrated tussock, African lovegrass)	Weed control	Ongoing weed management
Amtech	JEO9	Low (1)	Degradation by weed invasion and livestock activities	Weed management and livestock exclusion	Native grassland restoration

[3] Recorded as GSM site in AP28.

Name of the site by geographical area	***Site code (following the ACT Lowland Native Grassland Conservation Strategy, 2005)***	***Abundance of GSM observed in 2008/09 ****	***Threats to GSM identified in this and previous surveys***	***Recommended immediate action***	***Recommended long-term action***
Belconnen					
Dunlop Nature Reserve	BEO2	Low (7)	Urban expansion at edges, weed invasion and isolation from other large populations	Weed control (phalaris and Paterson's curse)	Secure current grassland size and increase connectivity
McGregor	BE03_A	Low (1)	Weed invasion (Chilean needle grass)	Until relationship between GSM and Chilean needle grass is established, no weed control	
Umbagong Park, Florey	BEO4	None	Wood and bush encroachment, weed invasion	Weed control	Tree and bush removal, continuous weed management
Lawson (ACT)	BEO7	None	Livestock grazing, weed invasion, urban development	Remove livestock and control weeds (saffron thistle, African lovegrass and serrated tussock)	Continuous weed management and maintain connectivity to BEO8
Lawson (Commonwealth) (2 sampling areas)	BEO8	Very High (23, 930)	Urban development and degradation through kangaroo overgrazing, weed invasion	Maintain moderate kangaroo population size, weed control (serrated tussock)	Weed control, habitat restoration and rehabilitation
Kaleen East Paddock[4]	BEO9	None	Horse grazing	Currently no immediate action required	Maintain as potential stepping stone to secure habitat connectivity to adjunct grasslands (GUO3)
Glenloch Interchange	BE11	None[5]	No biomass reduction	Reduce biomass	Maintain biomass reduction
Giralang roadside (2 sampling areas)	Not listed	Medium (1[6], 21)	Intense mowing, weed invasion	Weed control	Facilitate connectivity to BE08

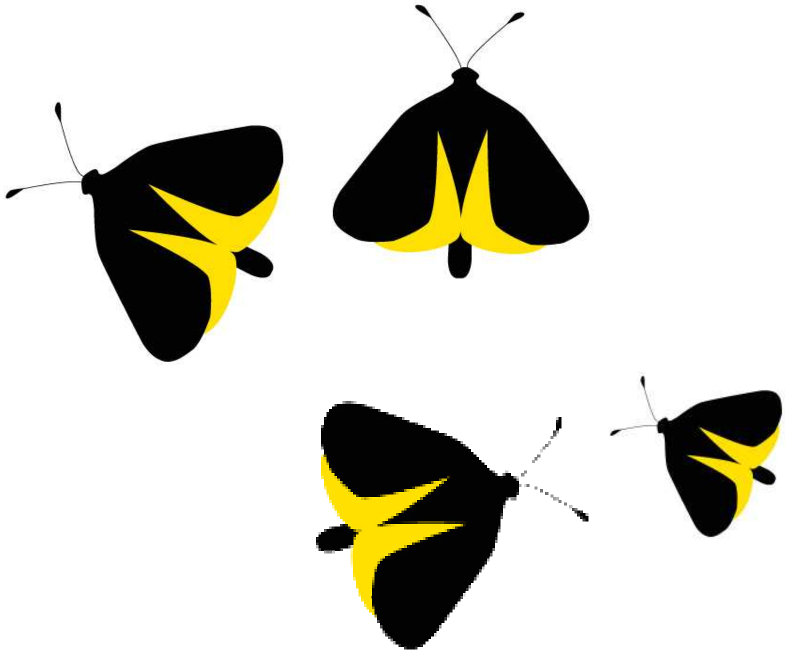
[4] Six plots were in Kaleen East Paddock and 6 in a horse paddock north of Ellenborough Street.
[5] Total calculated from 2 visits.
[6] Total calculated from 6 plots.

Name of the site by geographical area	*Site code (following the ACT Lowland Native Grassland Conservation Strategy, 2005)*	*Abundance of GSM observed in 2008/09 **	*Threats to GSM identified in this and previous surveys*	*Recommended immediate action*	*Recommended long-term action*
The Pinnacle	Not listed	None	Nil at present	Currently no immediate action required	
Canberra Central[7]					
CSIRO Headquarters, Campbell	CCO1	None	Weed invasion and exotic tree and shrub encroachment,	Weed control and tree/ bush removal	Native grassland restoration
Constitution Avenue, Reid	CCO2	Medium (38)[8]	Weed invasion and no biomass reduction, small site size	Reduce biomass	Restore buffer zone to stop weed encroachment and increase habitat size
Constitution Avenue, Reid	CCO2 (Exotic)	High (105)	Weed invasion (Chilean needle grass)	Until relationship between GSM and Chilean needle grass is established, no weed control	Monitor population dynamics in Chilean needle grass habitats
St Marks, ACCC, Barton	CC04	Low (5)[9]	No biomass reduction	Grassland recently burnt	Maintain biomass reduction
York Park, Barton (2 sampling areas)	CCO5	Very High (76[10], 413)	Urban development and weed invasion, lack of biomass reduction	Control weeds, reduce biomass Install information sign about native grassland and GSM	Increase connectivity
Lady Denman Drive, Yarralumla	CCO7	Medium (33)[11]	Small site size and isolation	Survey for adjunct populations (Royal Canberra Golf Club course)	Increase connectivity
Dudley Street, Yarralumla	CCO8	Very High (320)[12]	Small site size, weed invasion	Currently no immediate action required	Increase connectivity
Dudley Street, Yarralumla	CCO8 (Exotic)	Very High (685)	Weed invasion through Chilean needle grass	Until relationship between GSM and Chilean needle grass is established, no weed control	Monitor population dynamics in Chilean needle grass habitats

[7] Moths have also been observed in Yarralumla south of Alexandrina Drive between Novar Street and Hopetoun Circuit; south of Guilfoyle Street; and in an area running from the bicycle path beside the Molonglo River to Lady Denman Drive (and along it), and continuing on both sides of Cotter Road as far as Denman Street.
[8] Eleven plots surveyed at one visit.
[9] Total calculated from 3 visits.
[10] Total calculated from 3 visits.
[11] Total calculated from 2 visits.
[12] Total calculated from 3 visits.

Name of the site by geographical area	*Site code (following the ACT Lowland Native Grassland Conservation Strategy, 2005)*	*Abundance of GSM observed in 2008/09 **	*Threats to GSM identified in this and previous surveys*	*Recommended immediate action*	*Recommended long-term action*
St Johns Church, Reid	CCO3	Moths observed here on 11 Dec. 2008.	Fragmentation and weed invasion	Control weeds	Increase patch sizes and connectivity
NSW SITES					
Gundaroo Common	n.a.	None Some moths seen outside sampling areas.	Currently no information available	Currently no information available	Currently no information available
Queanbeyan Nature Reserve (2 sampling areas)	n.a.	Low (2, 2)	Intensive kangaroo grazing, herbicide spraying	Continue current management	Continue current management
Lulilly Pass Road, Collector	n.a.	None	Nil at present	Currently no immediate action required	

*Abundance classes are based on the total number of adults counted during site visits at 12 random points with circular spot counts method in 2008/09. Low (1-20), Medium (21-50), High (51-100), Very High (several hundreds). Numbers in brackets indicate the total moth count. Where there was more than one sampling area at a site, the higher (highest) number was rated.

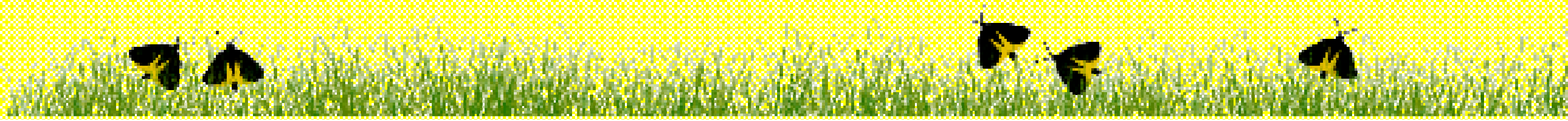


It's not a 9-5 job. It's an every moment you're awake job because you actually enjoy the work that you're doing.
Jeffrey Kalmikoff

Future Golden Sun Moth monitoring

- What have we learned from the pilot study?
- Ideas and suggestions for future Golden Sun Moth monitoring

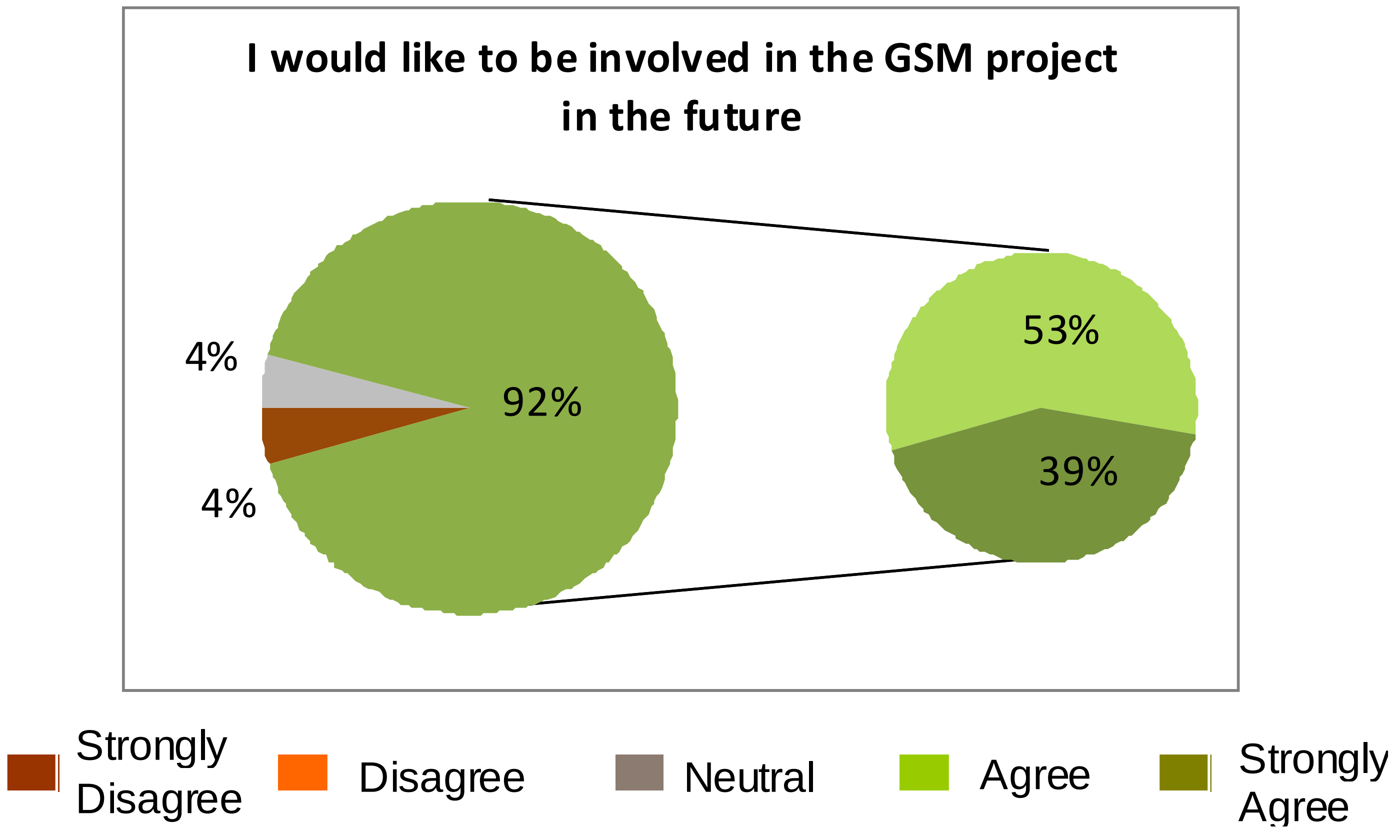
Future Golden Sun Moth monitoring



What have we learned from the pilot study?

Almost all participants felt that they had contributed to the conservation of the GSM and their habitats and expressed an interest in being involved in future GSM monitoring projects (Figure 8). The project contributed successfully to community capacity building and reached a wide public audience. There was great interest in community participation in a program involving an endangered insect species. Each of the 37 participants spent approximately 22 hours in training, workshops, field work and recording during the six week project.

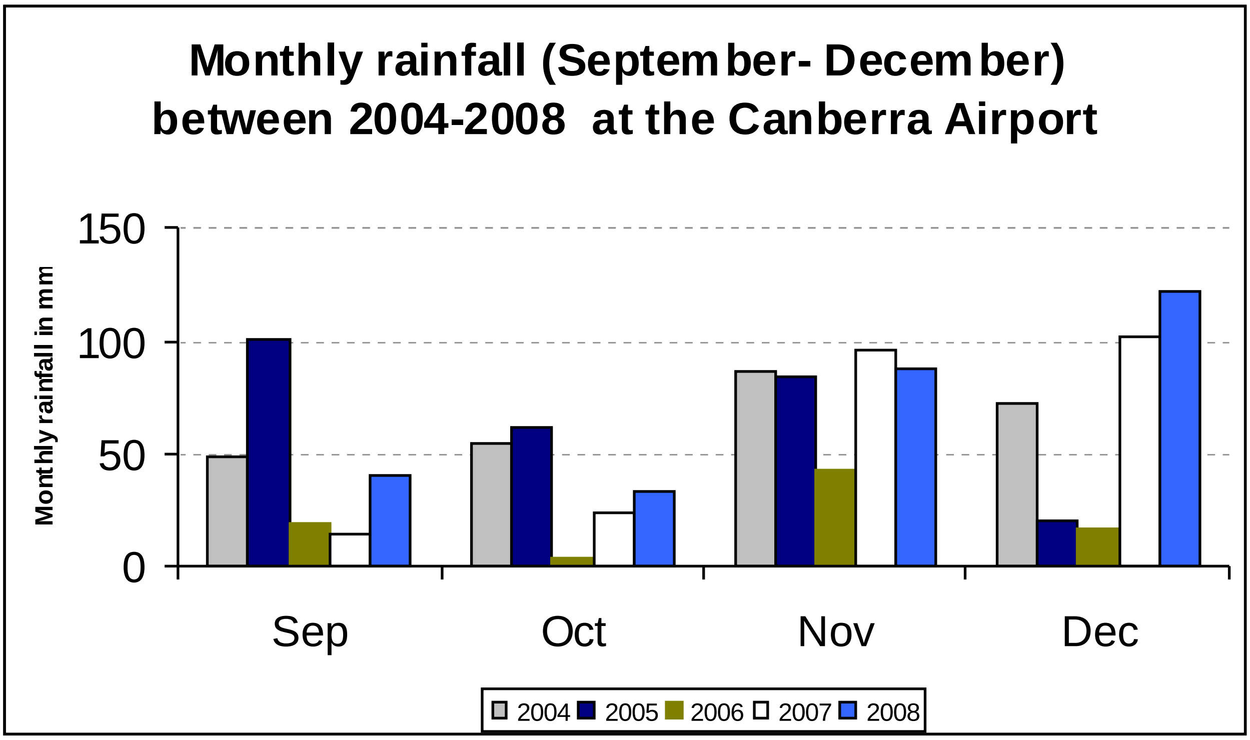
Figure 8. Level of interest among participants in future involvement in Golden Sun moth monitoring



According to our questionnaire, the greatest challenge for the participants was the difficulty of matching the time they had available to conduct the surveys to the times at which the moths were flying. The moths can be seen flying in the ACT region between the end October and mid January during the hottest part of the day between 11 am – 3 pm (A. Richter, unpublished) on warm to hot, cloudless and slightly windy days.

Two difficulties arise with this very limited window of activity by the GSM. Most people have personal commitments between 11 am - 3 pm during the week and are only available to volunteer on weekends, which do not always provide the most suitable weather conditions for GSM surveys. The spring and summer months during the GSM season in 2008-09 were characterised by cold and rainy weather conditions. The meteorological station at Canberra Airport recorded cool days with maximum temperatures well below the average and well above the average rainfall for December in 2008. Although there were plentiful sunshine hours, the weather conditions were not 'perfect' for the GSM during the duration of the project (Figure 9).

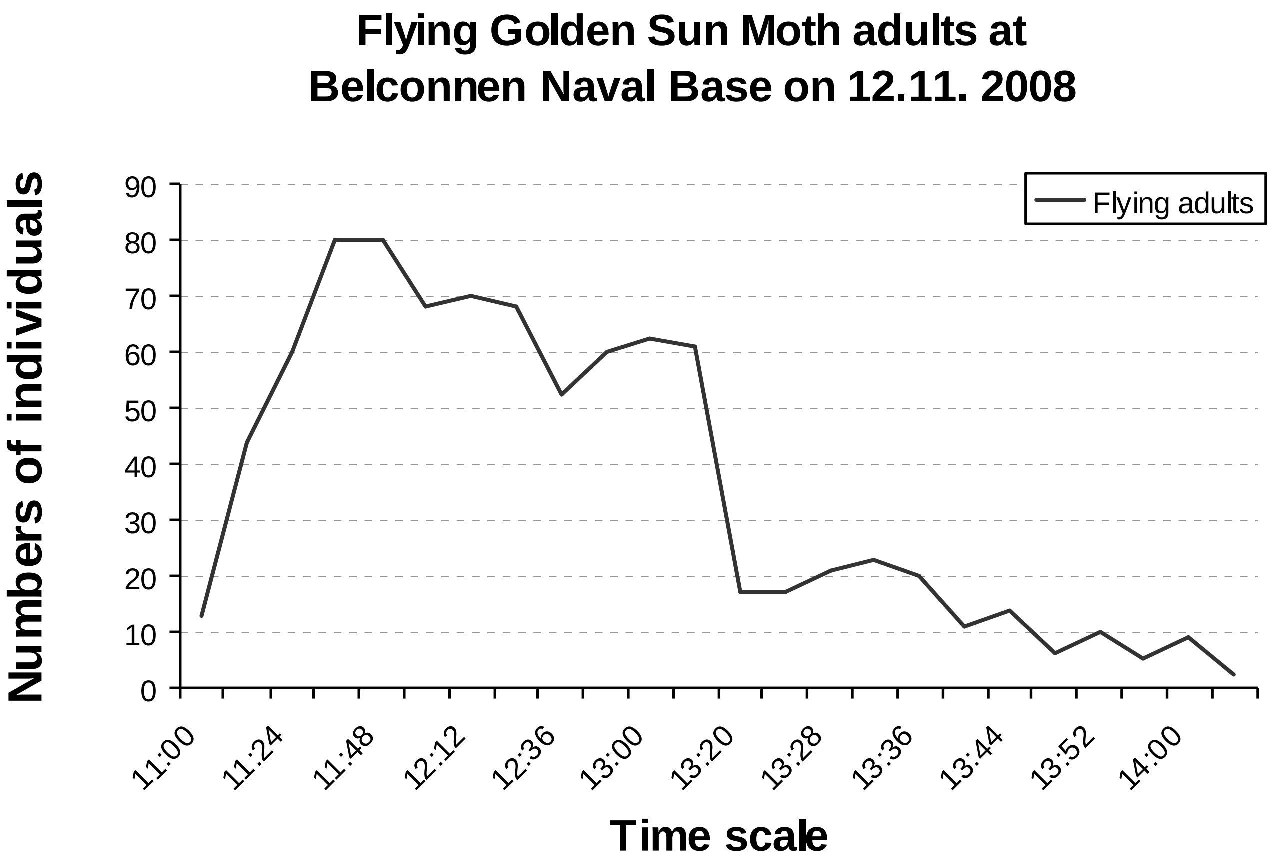
Figure 9. Monthly rainfall at Canberra Airport, September – December 2004-08



The literature refers to the moth's flight activity from about mid November until early January. Between years there is seasonal variation with flights occurring earlier in a warm dry spring and later and extending in a cool moist spring (Cook and Edwards 1994). As a result of cold and rainy days during November and December 2008, which presumably delayed moth emergence, active male and female moths were detected until mid January 2009.

The appropriate timing of the surveys is essential in order to estimate the relative abundance of *S. plana*. The hourly activity pattern in one of the largest GSM populations at the Belconnen Naval Base shows that the moths are most active between 11:30 am and 1:30 pm (A. Richter, unpublished data) (Figure 10).

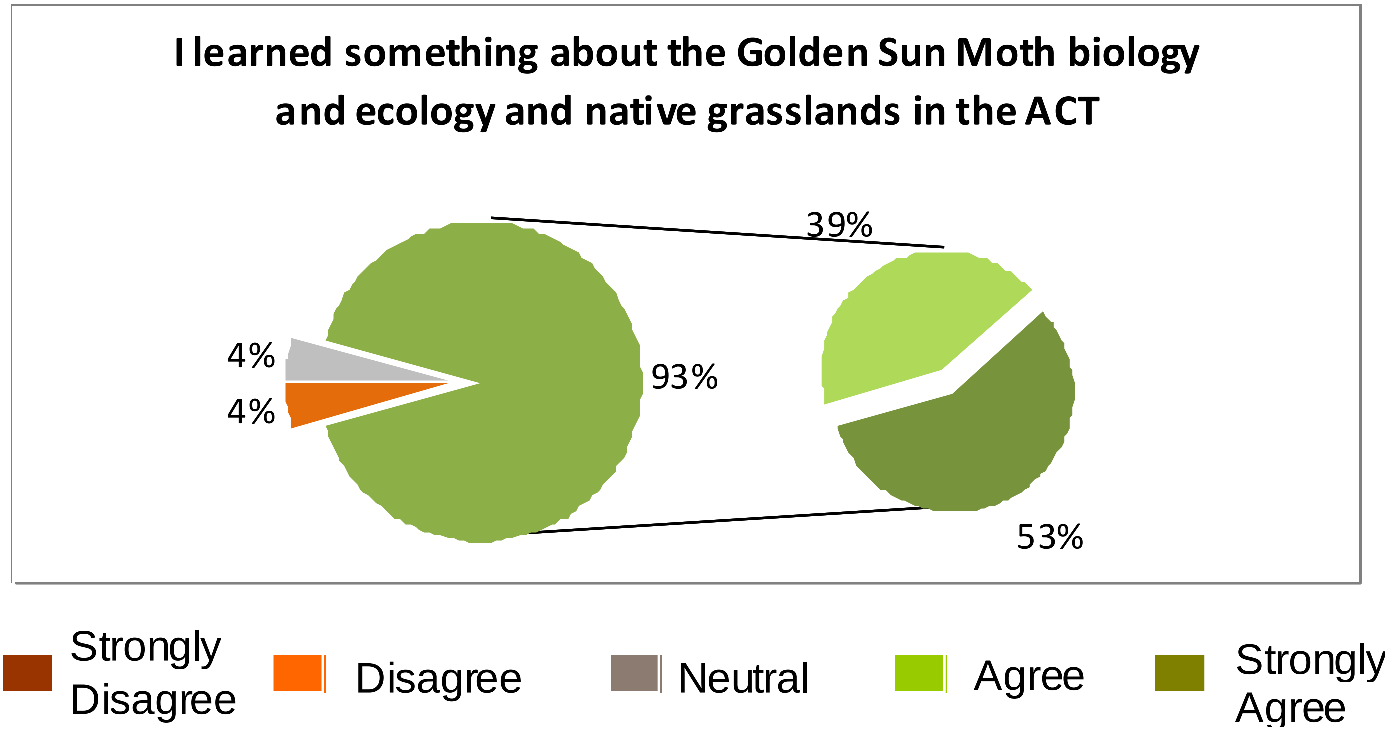
Figure 10. Flying time of Golden Sun Moth adults at Belconnen Naval Station, 11 am – 2.04 pm, 12.11.2008. Data collected by Dana Weinhold.



Many participants reported occasionally seeing moths in grass tussocks and flying away as they walked to the survey plots; by the time they reached the plots they counted no moths.

We received very positive feedback on the workshops and training sessions and considered them to be essential components in future monitoring programs. The aims of the workshops were to introduce the project, to highlight the importance of monitoring programs, to train the participants in species detection and to discuss concerns among the participants relating to the project (Figure 11).

Figure 11. Participants' rating of the material presented at workshops



Participants reported having encountered a number of difficulties. Firstly, the maps that we provided, which showed the location of each survey area and the associated study plots, were considered helpful for some sites but not in other areas that lacked significant landmarks. In addition, participants found it challenging without assistance to set up the plots using the materials provided in the monitoring kit (map, marking sticks, jars, and recording sheets). Some participants reported that re-finding the marked plots on subsequent visits (n=4) was somewhat problematic due to the random location of the plots, tall grass, lost site markers and interference by animals (horses/cattle).

The actual moth count and the identification of pupal cases in the field were considered feasible. Due to the moth's unique colour pattern and distinctive flying behaviour and the workshop introduction to the species with presentations of photos and pinned individuals, participants easily identified flying adults. The accuracy of estimating the relative abundance of the GSM was not evaluated during the project but is recommended for future monitoring. With most counts where there were large abundant populations, the counting method was varied by increasing up to 10 the number of circular counts made per plot in order to average the total number of moths that were counted within the predefined radius.

All pupal cases that were considered to be GSM by the participants were recorded, collected and kept for later checking. Most pupal cases were correctly identified. However, a minor proportion (<2%) of pupal cases did not belong to the GSM (Figure 12) and was mistakenly identified as *S. plana*.

Figure 12. Female Golden Sun Moth pupal case (left) and other invertebrate case (right), misidentified as *Synemon plana* case

Ideas and suggestions for future Golden Sun Moth monitoring

The following modifications to the monitoring program are suggested:

Earlier start in the season

- It is recommended that GSM monitoring program commence at the beginning of October. By mid October, participants should have been trained to identify *S. plana*. As soon as the moths are active, field training sessions with the moths present are essential. It is recommended that the survey plots to be set up and marked prior to the start of monitoring.

Simpler aims and objectives

- We recommend a simplification of the aims and objectives in future GSM programs. This should involve recording only the presence and absence of the species during a standardised amount of time spent on the site. Only sightings under appropriate weather conditions are considered as reliable and the absence of the moths needs to be confirmed by conducting at least three repeat visits. Pupal cases provide independent confirmation of the presence of the moths and unlike the outcomes of flying moth counts, are independent of climatic conditions.
- In order to simplify the project we suggest having the plots set up and vegetation surveys undertaken by a full time employed project coordinator and volunteers that have undertaken to do the vegetation surveys, as these tasks require special skills. Any participant that is not skilled in plant identification should be encouraged to join the vegetation team and be trained.

Stratified design

- One major improvement that we are suggesting is the establishment of permanent plots where selected key populations and key GSM habitats are monitored regularly. This new approach has the advantage of enabling changes over time within the populations to be detected. Other grassland sites would be monitored on a less intensive basis.

The authors of this report are still absorbing the many findings and are keen to refine the procedures used in the survey and find ways of undertaking a suitable community-based monitoring effort in future, working with government and landholders. Our plans for monitoring during the summer of 2010-11 involve trialling simplified survey procedures during visits to grasslands not surveyed in 2008/09, and to large ones not adequately surveyed. We are also continuing to work on the design of procedures for the more detailed monitoring of a number of permanent sites where GSM are known to occur.

Acknowledgements

First of all we would like to acknowledge all participants for showing such a great interest in, and enthusiasm for, the conservation of the GSM and its habitat - the native grasslands. Their active involvement in this pilot monitoring study and their willingness to spend many hours in workshops and in the field are greatly appreciated.

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The volunteers who were involved with the monitoring were:

Frank Antram	Mark Hall	Anett Richter
Mary Appleby	Eleanor Hearder	Cathy Robertson
Adrienne Carpenter	Lynne Heffernan	Geoff Robertson
Ian Clark	Sarah Hnatiuk	Alison Rowell
Margaret Considine	Anna Lashko	Andy and Janet Russell
Emma Cook	Nola McKeon	Sam Walker
Cathy Crozier	Ian McVay	Tess Ward
Rosamund Dalziell	Michael Mulvaney	Chris Watson
Meg Doepel	Kris Nash	Dana Weinhold
Pam Fawke	Margaret Ning	David Wong
Madeleine Fletcher	Will Osborne	Matthew Young
Matthew Frawley	Rod Pietsch	
Sybil Free	Stewart Pittard	
Jean Geue	Kim Pullen	

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List of available documents

The following documents are available on request from Friends of Grasslands

- Presentations given at training workshops and to report results to participants at the end of the survey
- Field recording sheets and explanation of their use
    - For moth and pupal case counts
    - For vegetation characteristics (abundance and cover)
    - For feedback from volunteers at the end of the project
- Newsletters

Contact Friends of Grasslands at PO Box 987, Civic Square, ACT 2608, on 02 6241 4065 or 02 6251 8949, or at **info@fog.org.au**.

For additional information about this project, you may visit the Golden Sun Moth web site (http://aerg.canberra.edu.au/teams/osborne/moth-count/?page_id=22).

ARCHIVAL RECORD

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Prepared for the Biodiversity Policy and Programs Branch Victorian Department of Sustainability and Environment,
University of Canberra,
Canberra

Dietary specialisation in the Golden Sun Moth *Synemon plana* - the key to understanding habitat requirements and site rehabilitation for this critically endangered species

Final report to

Biodiversity Policy and Programs Branch
Victorian Department of Sustainability and Environment

by

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University of Innsbruck (Austria)

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Female Golden Sun Moth (*Synemon plana*)

TITLE: Dietary specialisation in the Golden Sun Moth *Synemon plana* - the key to understanding habitat requirements and site rehabilitation for this critically endangered species

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ABSTRACT

This research is the first to describe the diet of the critically endangered Golden Sun Moth *Synemon plana*. The research included field work in the ACT and in Victoria (Altona North and Sugaloaf near Yea) and a very extensive component of molecular analysis and non molecular analysis conducted at the University of Innsbruck, Austria. The aim was to establish some understanding of the extent of dietary specialisation in this poorly known moth that was believed to be entirely dependent on *Austrodanthonia* grasses (wallaby grasses). The research combined field observation, molecular and stable isotope analyses to determine the composition of the diet of the Golden Sun Moth. This was by necessity confined to the larval stage, as the very short-lived adults do not feed. An attempt was made to determine the kinds of host plants used by the species. The study also addressed the very interesting issue as to whether the Golden Sun Moth also feeds on the exotic Chilean Needle Grass (*N. neesiana*).

When the project commenced the larvae of the Golden Sun Moth had not been described morphologically (taxonomically) so there was no key available for identifying the larvae in the field. Correct identification of the larvae was a key component of the project. This was done successfully by means of DNA barcoding to confirm the correct identification of the larvae by comparison of DNA sequences between larvae and adults. This then provided a reliable bench mark for the rest of the research, and ensured that other species of insects were not inadvertently included in the samples. The reference collection then enabled the correct identification of invertebrate larvae and pupae. To address the aims of the dietary study we successfully extracted DNA from 23 species of Australian plants that occur in the habitats of the Golden Sun Moth. We also developed a method for extracting the plant DNA from the larvae of the Golden Sun Moths. This procedure was complex and included examining whether the outer skins of the larvae may have been contaminated with plant DNA (i.e. plant material they brushed against but had not eaten).

Stable isotope analysis revealed that Golden Sun Moths feed on a range of C3 plants (*Austrodanthonia, Austrostipa, Nassella*) and apparently avoided C4 plants like Kangaroo Grass (*Themeda*), Redleg Grass (*Bothriochloa macra*) and Hairy Panic (*Panicum effusum*) as well as the introduced African Love Grass (*Eragrostis curvula*). Host native grasses have at this stage been identified to two genera – *Austrostipa* (spear grasses) and *Austrodanthonia* (wallaby grasses). These results will be refined by further analysis.

Our results indicate that the underlying pattern of the preference by the Golden Sun Moth for native grass species and the exotic Chilean Needle Grass is related to the photosynthetic pathway of these plants. All species of grass that were detected as being part of the diet of the Golden Sun Moth are classified as C3 plants. By contrast, grass species classified as C4 species were not present in the diet of the Golden Sun Moth and are most likely avoided by the species. Since we did not test the less common species of plants present in the habitat of the Golden Sun Moth, our findings do not represent the

full range of potential host plants. Further research is required to examine this, although the field observations provided a strong indication that wallaby grasses and spear grasses are the key hosts.

Our finding of a dietary preference for C3 grass species over the consumption of C4 grasses in Golden Sun Moth has significant implications for the future conservation and management of this critically endangered species. Climate change is expected to impact on the food available for many herbivorous species. Plant ecologists generally agree that the distribution (proportional occurrence) of C3 and C4 plants around the world will change with the predicted drier and hotter weather and increasing atmospheric CO_2. For the temperate grassland biome it is predicted that C3 plants will be replaced by a dominance of C4 plants. This could have dramatic consequences for herbivorous species that are dependent on C3 plants. The reduced availability of food plants will be compounded for species that share life traits of low dispersal ability and short life spans.

The Golden Sun Moth is characterised by very low dispersal ability and only lives for few days and has here been identified as feeding on C3 plants in larval stage. Because of this we suggest that the habitat of the Golden Sun Moth is potentially vulnerable to changes in the dominance of these plants as predicted to occur with climate change. Future conservation and management will need to consider the limited food availability for the Golden Sun Moth. The role of alternative food plants, including non native species, and the management of food resources for the Golden Sun Moth under climate change, as well as the effects of plant invasion needs to be considered.

INTRODUCTION

This report presents the results of research that aims to establish the extent of dietary specialisation in the critically endangered Golden Sun Moth (*Synemon plana*) (Figure 1), an unusual day-flying moth. The research is the first to describe the diet of the species and addresses one component of the recovery actions for the species (Department of Sustainability and Environment 2000). At this stage there is no recovery plan available for the Golden Sun Moth but the research will undoubtedly comprise an important objective of any recovery plan for the Golden Sun Moth.

The Golden Sun Moth *Synemon plana*

The Golden Sun Moth (*Synemon plana*) is arguably one of the most iconic species of moth found in natural temperate grassland in South-Eastern Australia (Zborowski and Edwards 2007). It has captivated considerable public attention because of its daytime flying habits, its bright golden wing markings, its rarity and its presence in native grasslands near large cities. The original natural habitat of the species is believed to have been natural temperate grassland, an ecological community characterised by a naturally treeless landscape such as occurs on the volcanic plains of southern Victoria and in the Canberra region. However, most of these grasslands have been lost to agricultural alteration and urbanization. Less than one percent of the former extent of some two million hectares remain today making it one of the most endangered vegetation communities in Australia (Kirkpatrick et al. 1995). As a consequence of this fragmentation and loss of habitat, the Golden Sun Moth was thought to have become locally extinct over most of its former range (Braby and Dunford 2006; Clarke and O'Dwyer 2000). Consequently the species was listed as threatened in Victoria under the *Flora and Fauna Guarantee Act 1998* and as critically endangered nationally under the Federal *Environmental Protection and Biodiversity Conservation Act 1999*. It is also listed as endangered in the ACT and NSW.

Loss of habitat – an ongoing concern

Based on the present day distribution of the Golden Sun Moth and the genetic structure of remnant populations (Clarke and Whyte 2003) the Golden Sun Moth is likely to have been widely distributed across south-eastern Australia, in association with suitable grasslands and grassy woodlands, at the time of European settlement. Broad scale losses, reductions, degradation and fragmentation of native grasslands has resulted in the local extinction and reduction of the species throughout its former range (Braby and Dunford 2006; Clarke and O'Dwyer 2000). The present day distribution of the species is restricted to small grassland remnants totaling to no more than a few hectares in Victoria (Gilmore *et al.* 2008), New South Wales (Gibson and New 2007; Gibson 2006) and the Australian Capital Territory (ACT Government 2005; Edwards 1994a). Despite its apparent rarity, recent surveys have detected populations at 15 locations to the north and west of Melbourne (Gilmore *et al.* 2008) and there are approximately 30 scattered small populations in the Australian Capital Territory (Edwards 1994; Richter 2010).

Interestingly, many sites that were found to have Golden Sun Moth adults by Gilmore *et al.* (2008) support habitat characteristics that have not been considered as suitable for the species in the past.

Despite conservation actions carried out to protect and conserve remaining Golden Sun Moth populations, the species is threatened by continuing losses of native grassland and fragmentation associated with agricultural, urban and industrial development. In addition, ongoing habitat degradation through changed grazing intensity, pasture improvement, weed invasion and changed fire regimes are considered to be major threats to the species (ACT Government 2005; Department of Sustainability and Environment 2008). These processes further reduce habitat functionality, and are considered to be major threats to the viability of the species (Department of Sustainability and Environment 2000) . Thus, the conservation and the management of the species is of national concern.

Figure 1 Female golden sun moth displaying its distinctive golden wings to attract the attention of male moths. Photo A. Richter

Ecology

Adult Golden Sun Moths can been seen between the end of October and mid January, only during the hottest part of the day (typically between 11 am and 3 pm) on warm to hot, cloudless and slightly windy days (Edwards 1993; 1994b). The life span of the adults is reported to be very short, with individuals surviving only a day or two. Males fly rapidly in a zig zag flight pattern about one meter above the grass sward searching for females. The female moths have bright orange-coloured hind wings that are used to attract males, while the female is sitting on the ground. Females are very weak at flying, and are usually observed perched or crawling rapidly on the ground – they are however capable of fluttering weakly just above the grass or ground and can move up to 20 metres in this way, although most movements comprise only a few metres (A. Richter and W. Osborne unpublished data). By contrast males fly quite strongly, and are able to fly distances of several hundred of metres.

Adult Golden Sun Moths lack functional mouthparts. Therefore, the species feeding behaviour is restricted to the larval stage. Current understanding of the diet of the species is based on observations of their pupal cases being observed near or within grass tussocks. The occurrence of empty pupal cases (Figures 2 and 3) near tussocks of particular species of native grasses indicates that it is very likely that the larvae feed exclusively on these species; in particular on Wallaby grasses (*Austrodanthonia* spp.) and Spear grasses (*Austrostipa* spp.) (Edwards 1994b). Despite the presence of the species in natural temperate grassland, several populations of Golden Sun Moth have been recorded in Victoria and the Australian Capital Territory (ACT) at grasslands sites dominated by Chilean Needle Grass (*Nassella neessiana*) - a South American noxious weed of national significance (Braby and Dunford 2006; Gilmore *et al.* 2008). Recent observations of flying adults and of larvae and pupae in highly disturbed grasslands (Gilmore et al 2008; Richter 2010) have lead to the hypothesis that a wider range of habitats may be occupied by the species and that this involves a broader host plant utilisation than previously thought.

Figure 2. Golden Sun Moth larvae pupating in situ at the base of a Wallaby Grass (*Austrodanthonia*) tussock. The discovery of large numbers of pupal cases in tussocks of species such as wallaby grass (*Austrodanthonia carphoides)*, tall spear grass (*Austrostipa bigeniculata)* and, more recently, the introduced Chilean needle grass (*Nassella neessiana)* provides a likely indicator of the host plants for the species. Photo W. Osborne

Figure 3 Close-up photograph of two Golden Sun Moth pupal cases (dorsal and ventral views). Photo. A. Richter

Background to the Dietary Analysis- molecular and non molecular approaches

Correct identification of larvae

Before commencing any species related investigation it is essential to correctly identify the species of interest – both the species under study (in this case the larvae of the Golden Sun Moth) and the host plants (in this case plant roots). No taxonomic description for the early (pre adult) life stages (egg, larvae, pupae) is available for the Golden Sun Moth. Instead identification is based on expert judgment by experienced entomologists (e.g. Ted Edwards CSIRO Entomology, Canberra) and by other reference material (e.g. larval material collected by A. Richter, University of Canberra). These identifications are based on morphological characteristics; in cases where the specimens are damaged, at an immature stage or in regions where taxonomic work has been hampered, many species remained unidentified

To improve confidence in the identification of larvae we applied the molecular method of DNA barcoding to correctly identify the larvae of the Golden Sun Moth. DNA bar-coding is a taxonomic method that uses a short genetic marker in an organism's mitochondrial DNA to identify the species and to differentiate the organism from other species (that sometimes are morphologically similar). This genetic technique has been

demonstrated to provide rapid and accurate species identification in insects (Work *et al.* 2005). This method has not yet been applied to Golden Sun Moths.
Generally, barcoding uses a ~600-700 bp long DNA sequence from s standard part of the genome to distinguish between two samples. The gene region being used as the standard barcode for almost all animal groups is the 5'-part of the mitochondrial cytochrome c oxidase I gene ("COI"). COI has proved to be highly effective in identifying birds, butterflies, fish, flies and many other animal groups. In plants three gene regions in the chloroplast; matK, rbcL and trnL, have been approved as the barcode regions for plant plants (Hebert and Gregory 2005). We decided to also use this novel approach in our project and applied COI sequences as a basis for animal identification (Golden Sun Moth adult and larvae identification) and the trnL gene as a basis for plant species identification.

Determining dietary specialisation

Information on trophic interactions is essential for our understanding of ecological processes such as population dynamics and ecosystem functioning (Cardinale *et al.* 2006). Assessing dietary consumption in endangered species is of particular interest for developing sound conservation strategies (Marrero *et al.* 2004). With respect to the Golden Sun Moth we have the extraordinary situation where an endangered species of lepidopteran was assumed to feed only on a very few species of native grasses in the genus *Austrodanthonia* but is currently found as adults and larvae in a wider range of grassland types including some grasslands infested by weeds (Gilmore *et al.* 2008). These observations indicate that the Golden Sun Moth may in fact use a broader range of food plants than was previously thought and is therefore not as specialised in its selection of host plants.

The most obvious approach to investigating the diet of an insect is to examine the species foraging behaviour under natural conditions or under standardised laboratory conditions. Direct observation of the feeding of the Golden Sun Moth is very difficult (nearly impossible) because feeding occurs in the soil (reportedly within the soil at the base of the host plant) and is therefore not visible or accessible. Laboratory experiments (feeding trials) might provide some insight into the species ability to consume different species. However, this approach may not reflect what actual feeding behaviour occurs under natural conditions. In the case of the Golden Sun Moth, attempts to establish and maintain the larvae in the laboratory have not succeeded (C. O'Dywer, University of Melbourne, personal communication). Thus, prior to the present study, direct observation of the presence of Golden Sun Moth pupal cases *in situ* near grass tussocks was the only reliable approach available for speculating about the diet of the moths.

Fortunately, as a result of recent advances in technologies, there are now alternatives available: Stable isotope analysis and molecular gut content analysis are alternatives to field observations and have been widely applied in the study of diet in soil-dwelling organism (for a review see King et al. 2008). Stable isotope analysis is the identification of isotopic ratios in animals and their diets and is considered to be a very useful technique for identifying the diet of animals, including insects that live below the soil

(Ponsard and Arditi 2000, Traugott et al. 2008). Generally, isotopes are atoms of the same element that differ in atomic mass due to differences in the number of neutrons contained in the atoms' nuclei. Stable isotopes, such as ^{14}N and ^{15}N (nitrogen) and ^{12}C ^{13}C (carbon), do not break down such as unstable (i.e. radioactive) isotopes. The application of stable isotope analysis in diet studies is based on the fact that the isotopic signatures present in the tissue of an animal is similar to the signature of the food it has eaten (i.e. the carbon signature) and that specific elements such as nitrogen get enriched upwards the food chain which allows to determine the trophic position of a consumer.

There are several clear advantages to the use of stable isotope analysis. The approach is reasonably straightforward, provides a reliable approach to the identification of the source of diet and enables an evaluation of the trophic position. However, stable isotope analysis usually does not provide a very high taxonomic resolution of the food and is therefore restricted in its application in dietary studies. This is in particularly the case when the full range of species making up the diet is of interest, as in the case of the Golden Sun Moth. However, stable isotope analysis is a useful component tool in a dietary study and provides valuable initial insight into the level of dietary specialisation.

Examination of complex trophic interactions requires the application of more sophisticated methods. Simple field observation and feeding trials under controlled conditions provide considerable insight into diet, but these approaches are not always applicable (for example for cryptic soil-dwelling species or species that cannot be kept in the laboratory). Molecular techniques have recently become available for ecologists for the detection of prey in guts, faeces and the regurgitations of predators Symondson 2002, King et al. 2008). Despite systematic improvements in molecular research over the last decade, the study of below-ground host plant-insect interactions involving invertebrate larvae is still proving to be technically very difficult. Difficulties with genetic approaches include a lack of genetic primer sensitivity, short post ingestion detection periods, cross- amplification problems and PCR inhibition (Staudacher et al. 2011).

The approach that we took included the use of both molecular techniques and stable isotope analysis to identify the diet in Golden Sun Moth larvae. Although the molecular approach using specific gene regions (e.g. for plants the trnL region) is a significant improvement in the identification of plant material in the guts of insect species, this method has also its limitations (Miquel et al. 2009). A major limitation is the resolution of plant species identification which does not always reach species level (Miquel et al. 2009). In cases of insufficient resolution in species identification, scientists recommend applying multiple approaches. For example, Valentini et al. (2009) suggest complementing the universal primer approach by one or several additional systems, specifically designed for amplifying short and variable region in the interested genera.

A combination of various approaches is recommended as a means of overcoming these limitations. In our project we followed this advice and combined molecular and non molecular approaches (stable isotope analysis) to examine the diet of the Golden Sun Moth. The risks involved in the project are briefly considered below.

Aims and objectives

The key ecological information lacking in our understanding of the ecology and conservation of the Golden Sun Moth is an understanding of its diet and larval development – this is essential for understanding the habitat requirements of the species. The finding of large populations of Golden Sun Moths at sites previously considered to be unsuitable due to the dominance of the exotic Chilean Needle Grass (*Nasella neesiana)* provided an ideal opportunity to further assess the conservation needs of the species. In particular, there is need for the examination of the assumption that the species is reliant at all stages of its development (egg, larvae, and adult) on native grass species for the survival of regional metapopulations.

The overall aim of the project was to determine the diet of Golden Sun Moth larvae across a range of grassland communities and to test the hypothesis that the species is not restricted to feeding on native wallaby grasses (*Austrodanthonia* spp) and also utilises Chilean needle grass.

The specific project objectives were to:

- Conduct field observations on the larval biology of Golden Sun Moths.
- Identify the larvae at a molecular level based on DNA barcoding to confirm the species identification.
- Develop protocols for DNA extraction from Golden Sun Moth adults and larvae as a basis for future molecular diagnostic analysis.
- Develop protocols for DNA plant extraction and gut DNA extraction as basis for further molecular analysis.
- Design and apply molecular and stable isotope approaches to identify the plant species used by Golden Sun Moths.

METHODS

An outline of the steps taken in the research is given in Figure 4. We focused on methods suitable for dietary analysis in soil insect larvae. We performed molecular tests to examine the suitability of the samples collected. These tests included the development of DNA extraction protocols (and conditions), the performance of Polymerase Chain Reactions (PCR) and sample sequencing (see below for further information). After establishing and optimizing laboratory protocols, we developed genetic tools (e.g. PCR primers) to specifically investigate the diet of the Golden Sun Moth based on the screening of their gut contents. We also prepared samples for the analysis of stable isotopes and determined the isotopic signature of plant and animal tissue.

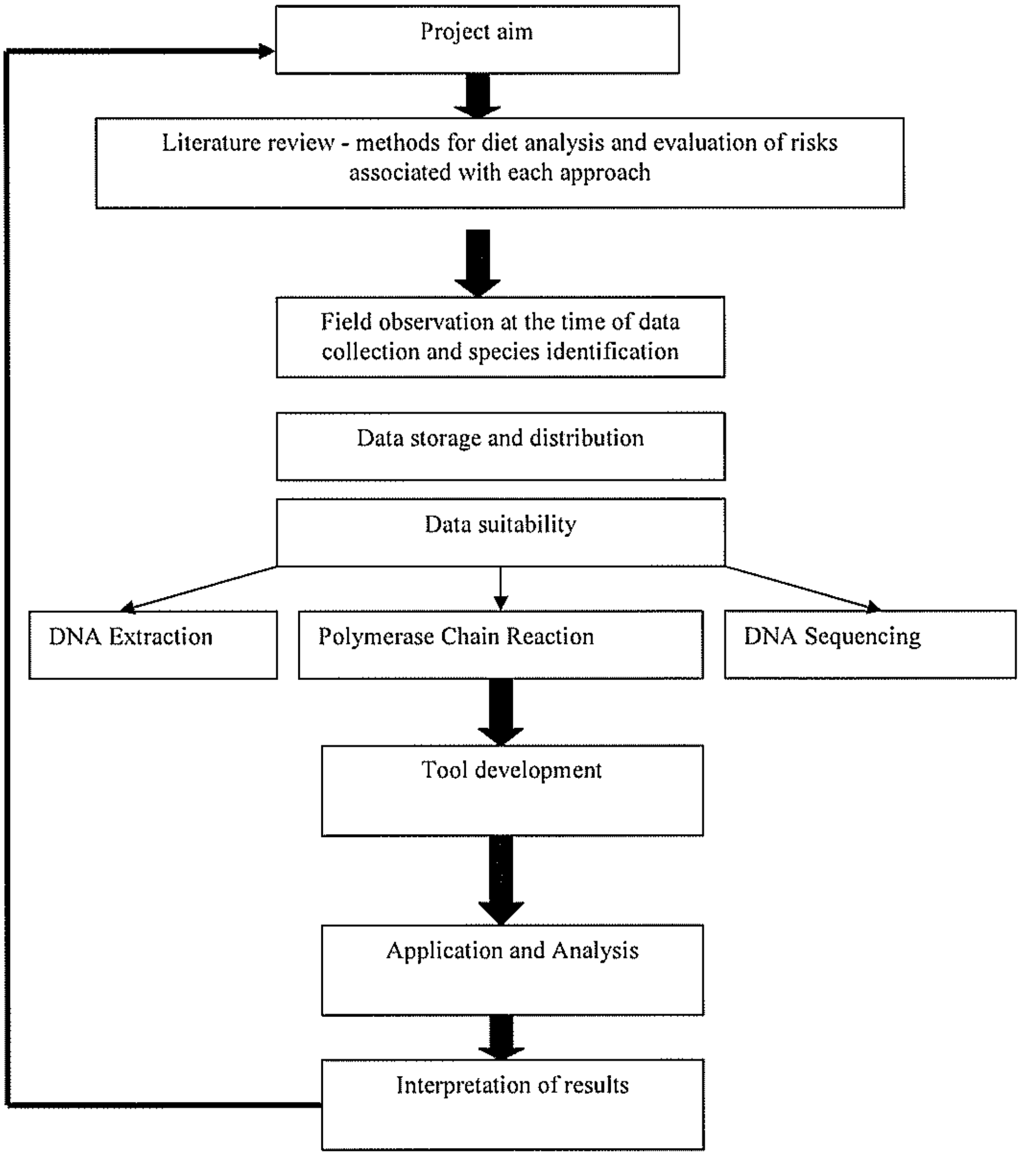


Figure 4 Hierarchical research design applied to the DNA component of the project.

Collection of larvae

We collected larvae in late autumn (April, May) and spring (September) between 2007 and 2009 at Altona North (T2A Industrial Estate) in Victoria and at various sites in the ACT (Belconnen Naval Base (Figure 5), McGregor and Dudley Street Yarralumla). Soil samples of approximately 20 x 20 x 10 cm were removed randomly with a small spade and the soil carefully searched for Golden Sun Moth larvae. Collections were made in both natural temperate grassland and in grassland dominated by Chilean Needle Grass. When any larvae were found, information on their location within the soil and feeding signs on roots systems were recorded (Figure 6). The dominant grass species were described for each soil sample, and for larvae still in situ in the soil, the roots of the grass species closest to the larvae were identified. All larvae found were brought to the laboratory, where their length and body weight were measured. All samples were stored at -80 C for further genetic analysis.

Both the Victorian and ACT locations are characterised by a mixture of native (*Austrodanthonia* and *Austrostipa* grass species) and non native grass species (Chilean needle grass) as well as including mixed forbs. All sites used supported large populations of Golden Sun Moths. These grasslands have not been ploughed or pasture improved through the application of fertiliser. Thus, we consider that samples used in our analysis are representative and our findings have general application to other sites with the species.

The initial identification of golden sun moth larvae was confirmed by an expert (Ted Edwards, CSIRO Division of Entomology, Canberra). Plant samples were collected from random locations in the ACT and included the dominant grass and forb species found in Golden Sun Moth habitats. These plant species included the expected host plants of the golden sun moth e.g. species of wallaby grass (*Austrodanthonia*), spear grass (*Austrostipa*) and the exotic Chilean needle grass. Each plant species was identified to species level with the assistance of local botanists (Isobel Crawford (Australian National Herbarium) and Greg Baines (ACT Parks and Conservation). Plant leaves and root material were stored in paper bags and oven dried for 24 h at 40 degrees. Each sample was kept separately in containers filled with silicate to prevent mould developing.

Figure 5 Wallaby Grass (*Austrodanthonia carphoides*) grassland at the (former) Belconnen Naval Station in the ACT. The Commonwealth Department of Defense removed soil contaminated with particles of lead-based paint from this location providing an ideal site for our searches for larval specimens. We searched for and removed all larvae before the site was disturbed by heavy earthmoving equipment so all larvae were in undisturbed locations in the soil. The photograph on the right shows a typical soil excavation (core) after soil was removed and used to locate larvae. Photos W. Osborne

Figure 6 Golden Sun Moth larvae in situ as observed during collection of soil. Photo W. Osborne

The plant samples that we collected were sent to the Institute for Ecology at the University of Innsbruck in 2009 for DNA extraction. Tissue obtained from adult Golden Sun Moths (muscle tissue from coxa and parts of the leg) also were sent to Innsbruck for DNA extraction in 2009. These samples were posted in vials after the specimens had been stored in ethanol for more than six months. Samples of Golden Sun Moth larvae were also sent to Innsbruck in 2009 – these had been dissected into smaller pieces and stored in DNA buffer solution to meet Australian government restrictions on the sending of specimens in ethanol on international freights. The samples were apparently delayed, arriving in Innsbruck ten weeks after they were sent from Canberra; unfortunately this resulted in damage to the DNA in the samples and they could not be used. In 2010 more Golden Sun Moth larvae were again sent to Innsbruck. To avoid the difficulties experienced in the previous year, we purchased a liquid nitrogen transport container for sending the tissues as frozen material. The samples arrived safely at the University of Innsbruck frozen and in very good condition and were transferred immediately into storage at -80 degrees.

DNA extraction and analysis

We applied two commonly applied DNA extraction methods in molecular dietary analysis, a "Chelex-based protocol" and a "CTAB-based protocol" for plant and animal DNA extraction. While the Chelex method is simple, cheap and fast to perform, it does not provide high quality DNA which is usually necessary for dietary analyses. The CTAB-method on the other hand is a complex extraction protocol which delivers high quality DNA, even from difficult samples such as soil-insects (Juen and Traugott 2005) During all steps in the DNA extraction we maintained sterile techniques to prevent other forms of contaminations (Figure 7). We used negative controls to monitor for cross-sample contamination during the extraction process. The extraction procedures follow protocols developed earlier: Chelex (Traugott et al. 2008) and CTAB (Juen and Traugott 2005)

Figure 7 Anett Richter working under sterile laboratory conditions at the University of Innsbruck during DNA extraction.

Polymerase chain reaction (PCR) protocol and optimization

The polymerase chain reaction (PCR) is used to amplify a single, or few, copies of a piece of DNA to generate thousands to millions of copies of a particular DNA sequence. Each PCR involves the application of primers. Primers are a strand of nucleic acid that acts as a starting point for the DNA synthesis and is essential to catalyse the DNA polymerases. In most cases, primers are short (15-30 bp) and chemically synthesized oligonucleotides. For the PCR process we used general plant and animal primers. Each PCR relies on thermal cycling, consisting of number of cycles of repeated heating and cooling of the reaction for DNA strand melting and enzymatic replication of the DNA. The cycling conditions are taxon-specific and depend on the quality of the DNA samples. Therefore, PCR conditions need to be optimized case by case. We optimized the PCR conditions for plant and animal samples through testing various annealing temperatures, DNA template concentration and primer concentrations.

To separate DNA strand according to their length and to visualize the amplification success of the DNA via PCR we performed standard agarose gel electrophoresis (e.g. Juen and Traugott 2005). After the electrophoresis is completed, the DNA can be visualized through staining with dys such as ethidium bromide or GelRed (Figure 8).

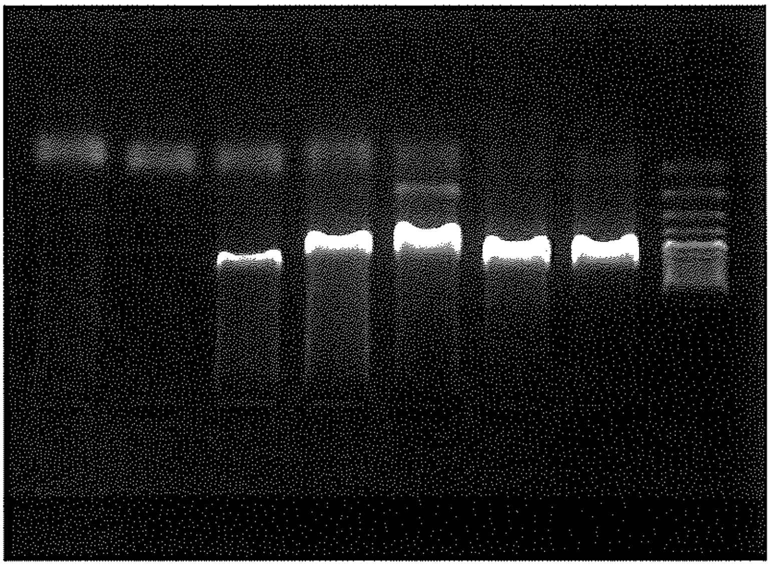


Figure 8 Digital photograph of an agarose electrophoresis gel. Each column represents one sample of DNA extract. The right column is the DNA ladder and indicates the lengths of base pairs.

Depending on the number of differently-sized DNA molecules, each lane shows one or more DNA bands which differ in their size (Figure 8). Bands in different lanes that end up at the same distance from the top contain molecules that passed through the gel with the same speed, indicating approximately the same size (length).

PCR reactions can fail in some cases (see lane 1 and lane 2 in Figure 8). One of the main reasons for 'a- none- positive PCR reaction' can be the presence of inhibitors in the DNA solution. Such inhibitors can be polysaccharides, proteins, phenolic compounds, and other uncharacterized plant secondary metabolites. In such cases, cleaning kits are available to clean the DNA extracts, such as silicate-based cleaning kits which we employed in our project (Juen and Traugott 2006)

PCR sequencing

After successful PCR, DNA sequencing determines the order of the nucleotide bases—adenine, guanine, cytosine, and thymine—in a molecule of DNA. Both Golden sun moth and plant DNA was sequenced in both forward and reverse directions using protocols established earlier (Traugott et al. 2008, Staudacher et al. 2011). Sequences were corrected manually and checked for similarity with published sequences in GenBank using the BLAST algorithm (http://www.ncbi.nlm.nih.gov/blast/Blast.cgi) and aligned with BioEdit sequence alignment editor 7.0.9 (Hall 1999).

Stable Isotope Analysis (SIA)

The analysis of stable isotopes is a powerful analytical method that can be used to examine the main sources of consumed food items and for confirming trophic position of heterotrophic organisms (West *et al.* 2006). The technique has been widely applied in dietary studies in aquatic, marine and shoreline ecosystems (Lajtha and Michener 1994; Peterson and Fry 1987) and on larger vertebrates (Nakagawa *et al.* 2007). However, there are only few studies which have employed this approach to study the feeding ecology of below-ground herbivores (Ponsard and Arditi 2000; Traugott *et al.* 2007, 2008). The two elements most often employed to address trophic ecology in this approach are carbon (C) and nitrogen (N), both of which have heavy isotopes (^{13}C, ^{15}N). Both isotopes are present (^{12}C, ^{14}N) in small amounts in the tissues of plants, animals, microbes and dead organic matter. Differences in the fraction of the heavy isotope in food sources are reflected in the consumer. Usually the carbon isotopic signature (δ^{13}C) reflects a consumer's source of dietary carbon (Peterson and Fry 1987; Post 2002). The trophic position of an organism within a food web can be inferred from the isotopic signature of the heavy nitrogen (δ^{15}N) because consumers usually get enriched in ^{15}N compared to their diet meaning that δ^{15}N values increase with higher trophic levels (Post 2002). Therefore, the combined measurements of ^{13}C and ^{15}N are commonly used to investigate food sources and trophic level of a consumer.

We used stable isotope analysis to obtain an overview of the δ (delta)^{13}C (carbon) and δ (delta)^{15}N (nitrogen) signatures of species of plants that are commonly associated with native and exotic habitats of the Golden Sun Moth. Then we analysed the carbon and nitrogen isotopic composition of larvae of Golden Sun Moths that were collected in native and exotic grassland for the comparison of the isotopic signatures of the plants present in the larvae.

A Consideration of Risks

The project faced a considerable level of risk because the molecular approaches used had not been previously trialed with Golden Sun Moths. To provide the best possibility of success, collaboration with the Institute for Ecology at the University of Innsbruck was essential. The Innsbruck group led by Dr Traugott is a world leader in the molecular determination of invertebrate diets; see http://www.uibk.ac.at/ecology/staff/persons/traugott.html. See also http://www.uibk.ac.at/ecology/forschung/australian_moth.html).

The identification of food preferences is made more problematic when the species of interest feeds on a range of different plants; based on our field observations, this was predicted to be the case for the Golden Sun Moth. The risk in this context is that potentially only a small fraction of the host plans spectrum will be identifiable and that the complete range of host plants may remain unknown. Another risk is that contamination could occur in the original samples or during the laboratory analysis. DNA degradation and contamination is a common risk in this kind of analysis. Based on these known risks we developed a mitigation strategy to reduce these potential risks (Table 1).

Table 1 Approach to risk mitigation applied to the dietary analysis

RISK	MITIGATION STRATEGY
Incorrect identification of larvae	Identification conducted by expert (Richter and Osborne) aided by the use of a reference collection. DNA bar-coding should confirm correct identifications
Larvae collected do not contain any gut contents	Initial collection of larval samples to be large enough to allow for this. Collection of alternative larval samples should be considered.
DNA in gut samples is highly degraded	Additional larvae will be collected
Larvae have not been stored appropriately, leading to highly degraded DNA	Additional sampling will be required Larvae will be stored on ice during transport to the laboratory and snap frozen within minutes of arrival at the laboratory.
Larvae have been damaged/destroyed during the process of storage (e.g. freezer failure)	Freezers have back up fail-safe mechanisms. Samples can be easily moved to alternative storage. Additional sampling will be required if a freezer fails and is not discovered. Alarm systems should alert users.

Species-specific prime development is not able to be used for the detection of several potential host plants	Additional funding would be required to develop species specific primers or to test alternative methods such as pyrosequencing.
Contamination by foreign DNA in the laboratory and results are compromised	Negative Controls carried out with each set of reactions for the early detection of contamination. Contaminated reactions repeated until negative controls are clear.
Failure to amplifier despite template DNA present	Positive controls runs each set of reactions of each species
Failure to amplifier or unintended amplification resulting from unknown intraspecific genetic variation in target region	Sequence samples from different geographic regions to confirm invariability

RESULTS

Field Observations

In November 2008 at Altona North 58 soil samples were randomly chosen and removed for individual searching. The dominant grass species represented in the soil samples collected during searches for Golden Sun Moth larvae at Altona North in Victoria were exotic Chilean Needle Grass (*N. neesina*), Tall Spear Grass (*Austrostipa bigeniculata*) and wallaby grasses (*Austrodanthonia* species).

Despite an intensive search of the soil in samples taken from beneath the 58 grass tussocks, only twelve large Golden Sun Moth larvae were found. Over half of these GSM larvae (n=7) were found within the root systems of Chilean Needle Grass tussocks. One third of the larvae (n= 4) were present in the root systems of Tall Spear Grass and one larvae was present in the roots of a mixture of *Austrostipa* and *Austrodanthonia* sp. (Fig 9).

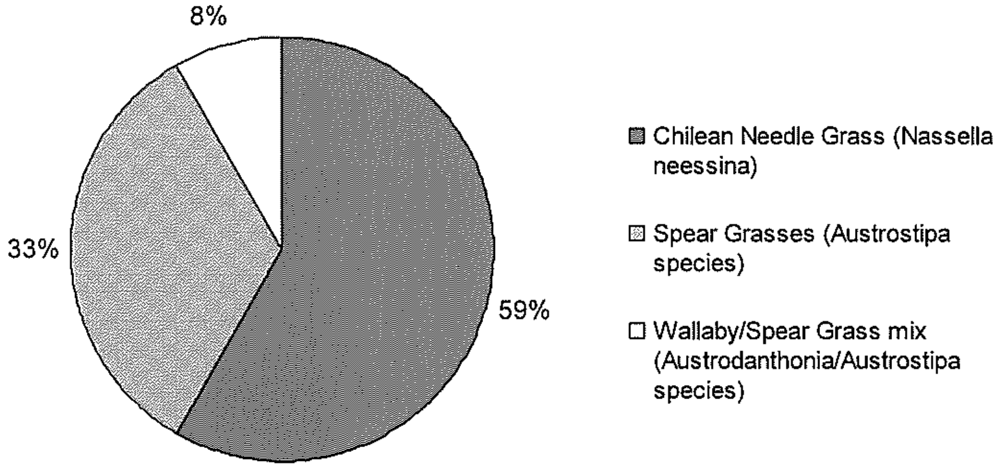


Figure 9 Occurrence of Golden Sun Moth larvae (in percentage) in relation to different species of grasses collected during a search for larvae in 58 soil samples in Victoria.

In the ACT, a total of 142 Golden Sun Moth larvae were collected from native and exotic grassland. Within the soil samples, these larvae were associated with Spear Grass *(Austrostipa bigeniculata),* wallaby grasses *(Austrodanthonia* species), wiregrass (*Aristida* spp) and Redleg Grass (*Bothriochloa macra*) as well as Chilean Needle Grass (*Nassella neesiana*) (Figure 10).

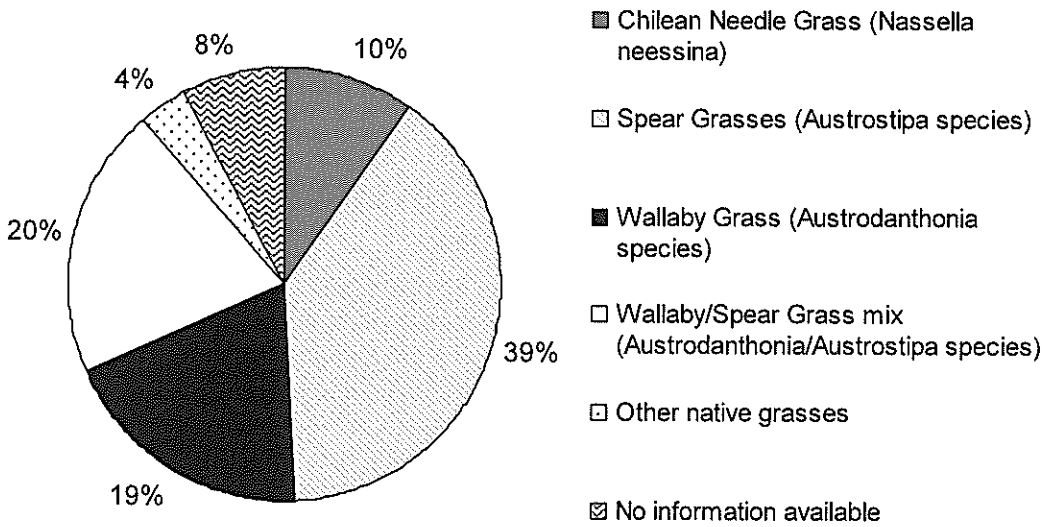


Figure 10 Occurrence of Golden Sun Moth larvae (in percentage) in relation to different species of grasses in the ACT.

The findings of the occurrence of Golden Sun Moth larvae among a range of native grass species (Spear grass, Wallaby grass and mixtures) and the exotic Chilean Needle grass in the ACT is similar to the findings of GSM larvae found in the root system of grass species in Victoria. Only two grass species (wiregrass (*Aristida sp.*) and Redleg Grass (*B. macra*) were not present in Golden Sun Moth habitat in Victoria at the time of data collection.

No obvious indications of the larvae feeding on roots were found when the larval burrows were examined during sampling. The mean depth at which the larvae were collected in the soil beneath the grass tussocks was 0.85 cm depth (range 0.3 to 4.0 cm) in winter and 3.2cm (range 0.3-5.0) in spring

The average length of the larvae was 18.2 mm (range 6 mm to 28 mm). Golden Sun Moth larvae collected in Chilean Needle Grass were significantly larger than larvae collected in natural temperate grasslands (F=12.515, df=1,80, p=0.001). Most larvae collected were at the uppermost end of a silk lined burrow (Richter 2010).

From our observations of the composition of the grass species found in a close proximity to Golden Sun Moth larvae, we suggest that the species is associated with at least the following genera and species of native grasses (*Austrostipa bigeniculata, Austrodanthonia* species including *A. carphoides)* and with at least one non native grass species (*Nassella neesiana*).

Confirmation of Identification of Golden Sun Moth Larvae using DNA Barcoding

The alignment of sequences of larvae Golden Sun Moth revealed a 100% fit of the nucleotides to sequences of adult Golden Sun Moth (Figure 11). This showed that the collected larvae actually are the juvenile stages of the Golden Sun Moth.

Development and Optimisation of DNA Extraction Protocols for the Grassland Plant Species

In order to identify the diet of the larvae it was necessary to develop protocols for DNA extraction from the grasses and forbs that were most abundant (dominant) at typical sun moth sites. In this component of the research we aimed to develop and optimise protocols for DNA extraction for Australian plant species associated with the habitat of the Golden Sun Moth and expected to be host plants for the species. We successfully extracted DNA from 23 species of plants by using CTAB extraction protocols and applying the general plant primers (Figure 12). This lead to the conclusion that general primers are sensitive for the Australian plant species and that the part of the trnL gene is suitable for further genetic analysis

Testing the Sensitivity of Plant Primer on Animal Tissue

This test was required to ensure that the plant primers do not amplify any animal tissue. If the plant primers are suitable, it should be possible to screen whole specimens (larvae) for the plant remains in the gut contents. We found that the general plant primer PCR assay for the plant species does not amplify DNA of Golden Sun Moths adults. The test shows that no plant DNA in animal tissue was detected at the lengths of our positive control- Chilean Needle Grass (*N. neessiana*) using general plant primers (Figure 13). On the basis of these findings we can conclude that the general plant primer assay can be used to test for plant DNA in Golden Sun Moth larvae extracts (extract that contains both, animal DNA and plant DNA from the gut).

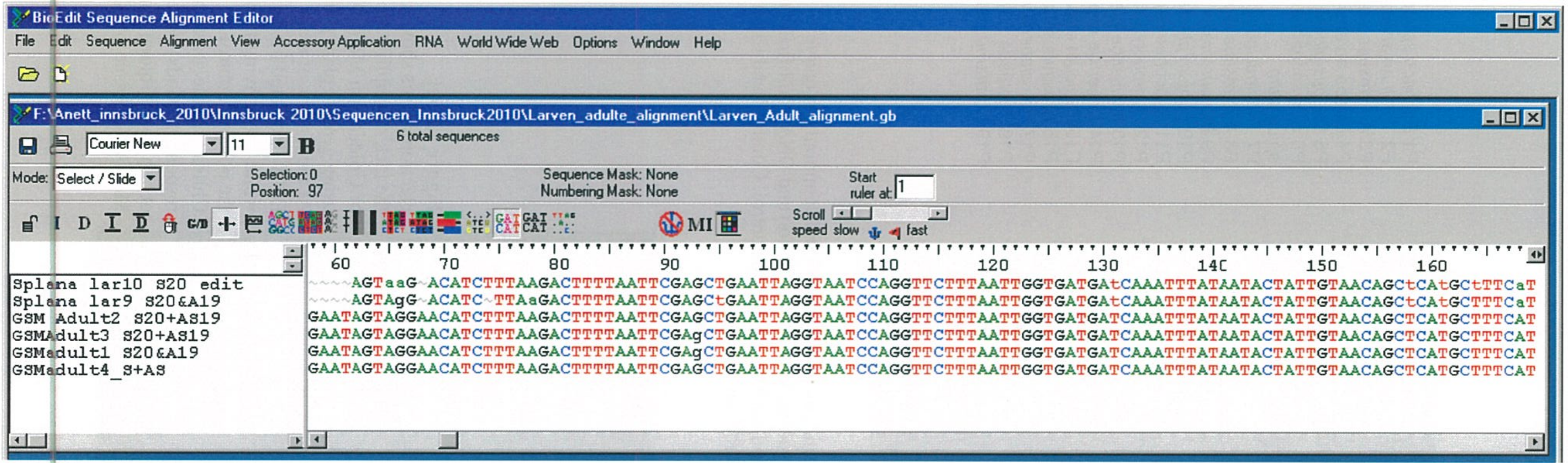
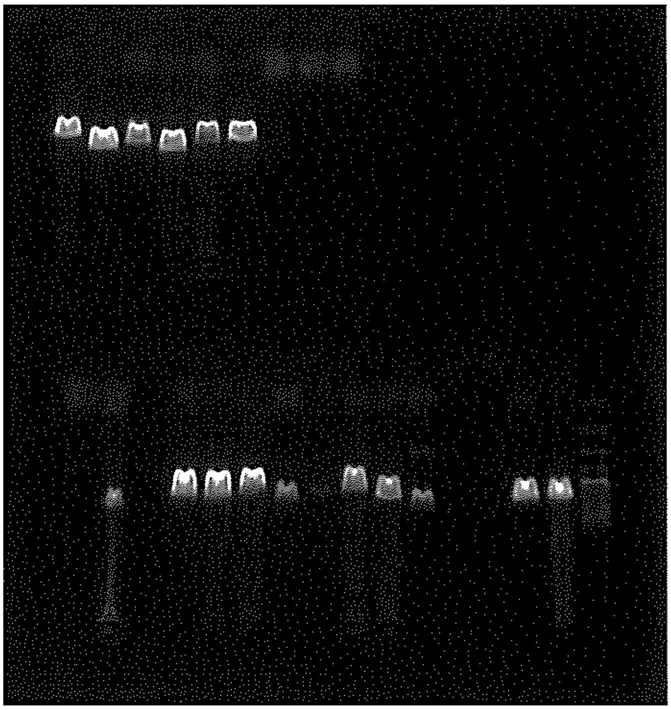


Figure 11 Copy of the alignment of Golden Sun Moth larvae and adults (GSM Adult) sequences in the program BioEdit. A complete correspondence 100% fit of the sequences is indicated by the similarity of base pairs (TAGC) among the sequences.



P1 *Euchiton sphaericus*
P2 *Trifolium arvense*
P3 *Austrostipa scabra*
P4 *Linaria arvensis*
P5 *Daucus glochidiatus*
P6 *Chrysocephalum apiculatum*
P7 *Triptilodiscus pygmaeus*
P8 *Austrostipa bigeniculata*
P9 *Bromus mollis*
P10 *Echium plantagineum*
P11 *Hypochaeris glabra*
P12 *Hydrocotyle laxiflora*
P13 *Wahlenbergia communis*
P14 *Deyeuxia quadriseta*
P15 *Panicum effusum*
P16 *Crassula sieberiana*
P17 *Poa sieberiana*
P18 *Themeda tiandra*
P19 *Carthamus lanatus*

Figure 12 Gel electrophoresis of nineteen species of plants found commonly in native grassland. Each light band indicates the successful DNA extraction and DNA amplification. Position 1 (a.d.) is the negative control and position 2 positive control. Control I and Control 2 upper line are controls for the DNA extraction.

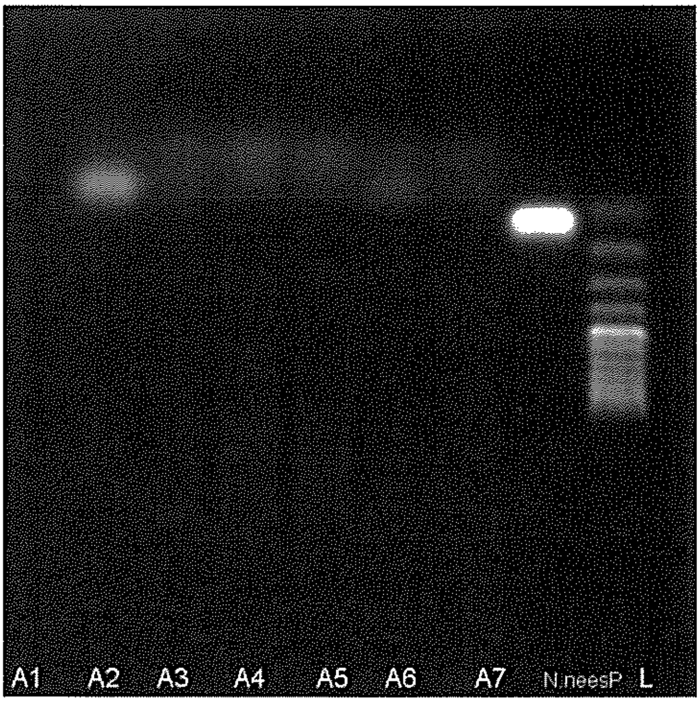


Figure 13 Gel electrophoresis showing the lack of amplification of Golden Sun Moth DNA using general plant primer. At the lengths of plant DNA (indicated by the white line arriving from the positive control Chilean needle grass) no responses (bands) were obtained on Golden Sun Moth adult tissue (A1-A7).

Testing for Plant DNA on the Outer Skin of the Larvae

When using complete Golden Sun Moth larval specimens for gut content analysis, it is essential to ensure that no plant material is attached to the outer body of the larvae, as this could contaminate the results. This was done by rinsing the larvae in buffer solution to remove any particles on the outer side of their body. The solution of buffer was then tested for the presence plant DNA using general plant primers. Our test revealed that four out of eleven larvae contained plant DNA on the outside of their body (Figure 14). This finding suggested that the 'bleaching' approach would be required to destroy non target DNA on the outside of each larvae.

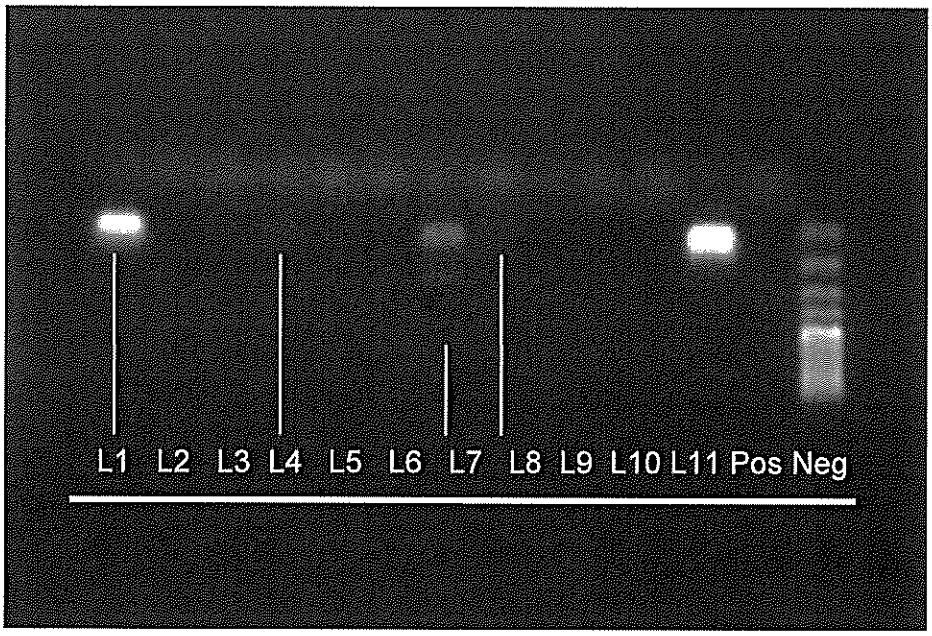


Figure 14 Gel electrophoresis of plant DNA present on the outer side (L1, L4, L7, L8) of Golden Sun Moth larvae

Extraction of DNA from the Gut Samples

Despite several months of lab work devoted to this part of the project, we were unable to successfully extract DNA from any of the larval gut samples. It is planned to repeat this work when additional larvae are obtained and if we can obtain further funding.

Testing for Dietary Specialisation by use of Stable Isotopes

We applied the method of stable isotopes to first obtain an overview about the δ (delta)$_{13}$C (carbon) and δ (delta)$_{15}$N (nitrogen) signatures of plant species that are commonly associated with native and exotic habitats of the Golden Sun Moth. Then, we analysed the carbon and nitrogen isotopic composition of larvae of Golden Sun Moth that were collected in native and exotic grassland for the comparison of the isotopic signatures of the plants present in the larvae.

The analysis of ^{13}C for the plant samples revealed that the delta $(\delta)^{13}C$ signatures ranged between -30‰ and -10‰ (Figure 15). The $\delta^{13}C$ signatures separated the plants according to their photosynthetic pathways (C3, C4). Plant species with signatures between -10‰ and -15‰ were identified as C4 plants, whereas C3 plants showed $\delta^{13}C$ signatures above -25‰. Four species of grasses had a C4 photosynthetic pathway: African Lovegrass (*Eragrostis curvula)*, Kangaroo Grass *(Themeda australis)*, Hairy Panic *(Panicum effusum*) and Redleg Grass (*Botrichloa macra)*. The remaining species (Chilean Needle Grass, Tall Spear grass and wallaby grasses and all forbs tested) are C3 plants (Figure 15). The analysis of the delta $\delta^{15}N$ signatures for plant species showed values ranging from -1.8‰ to 4.5‰ (Figure 16). We found no clear difference between the delta ^{15}N signature between native and non native plant species and between the $\delta^{15}N$ signatures between C3 and C4 plants (Figures 16, 17). With regard to the $\delta^{15}N$ signatures, we found a clear distinction between individuals of Golden Sun Moth larvae present in native and non native habitats (Figure 17).

The stable isotope analysis of Golden Sun Moth larvae tissue revealed that the individuals of Golden Sun Moth examined consumed C3 plants and excluded the ingestion of C4 plants in its diet. This finding is indicated by the distribution of the delta ^{13}C signature of Golden Sun Moth larvae in comparison to the distribution of the delta ^{13}C signature of plant species examined (Figure 17). None of the results for the larval tissue clustered with the isotopic signatures of the C4 plants. This leads us to conclude that the Golden Sun Moth larvae examined have not fed on Kangaroo Grass (*T. australis*), Redleg Grass (*B. macra*), Hairy Panic (*P. effusum*) and the exotic African Lovegrass (*E. curvula*). The larvae examined ingested exclusively the C3 grasses tested in our study. Grass species that were identified as C3 plants include the exotic grass Chilean Needle Grass (*N. nessiana*) and species of *Austrodanthonia* and *Austrostipa*.

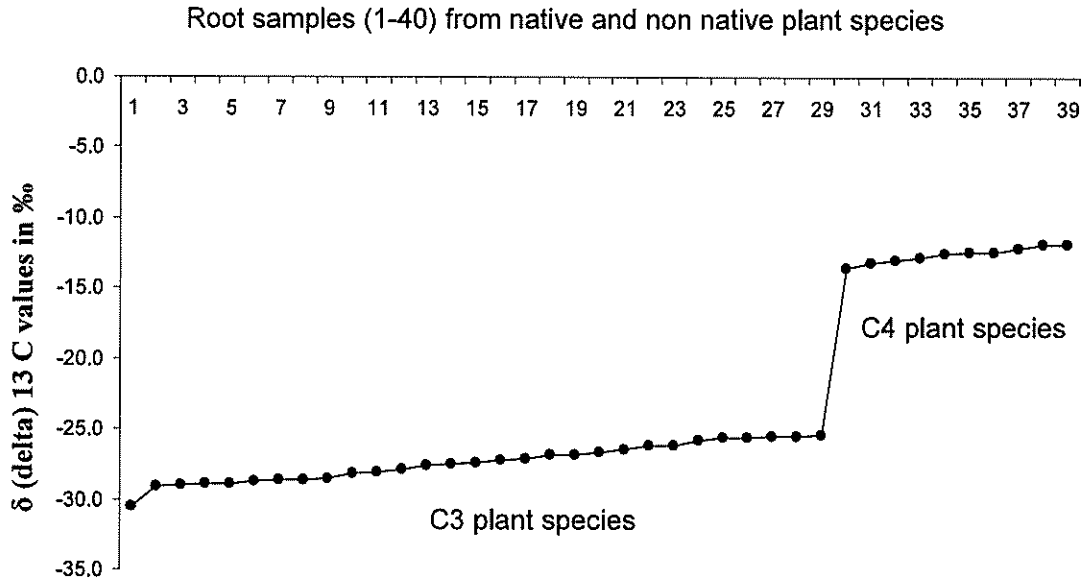


Figure 15 Delta (δ)^{13}C signatures of plant species (based on root samples) present in natural temperate grassland and grassland dominated by Chilean needle grass. Numbers indicate the species which can be found in the Appendix.

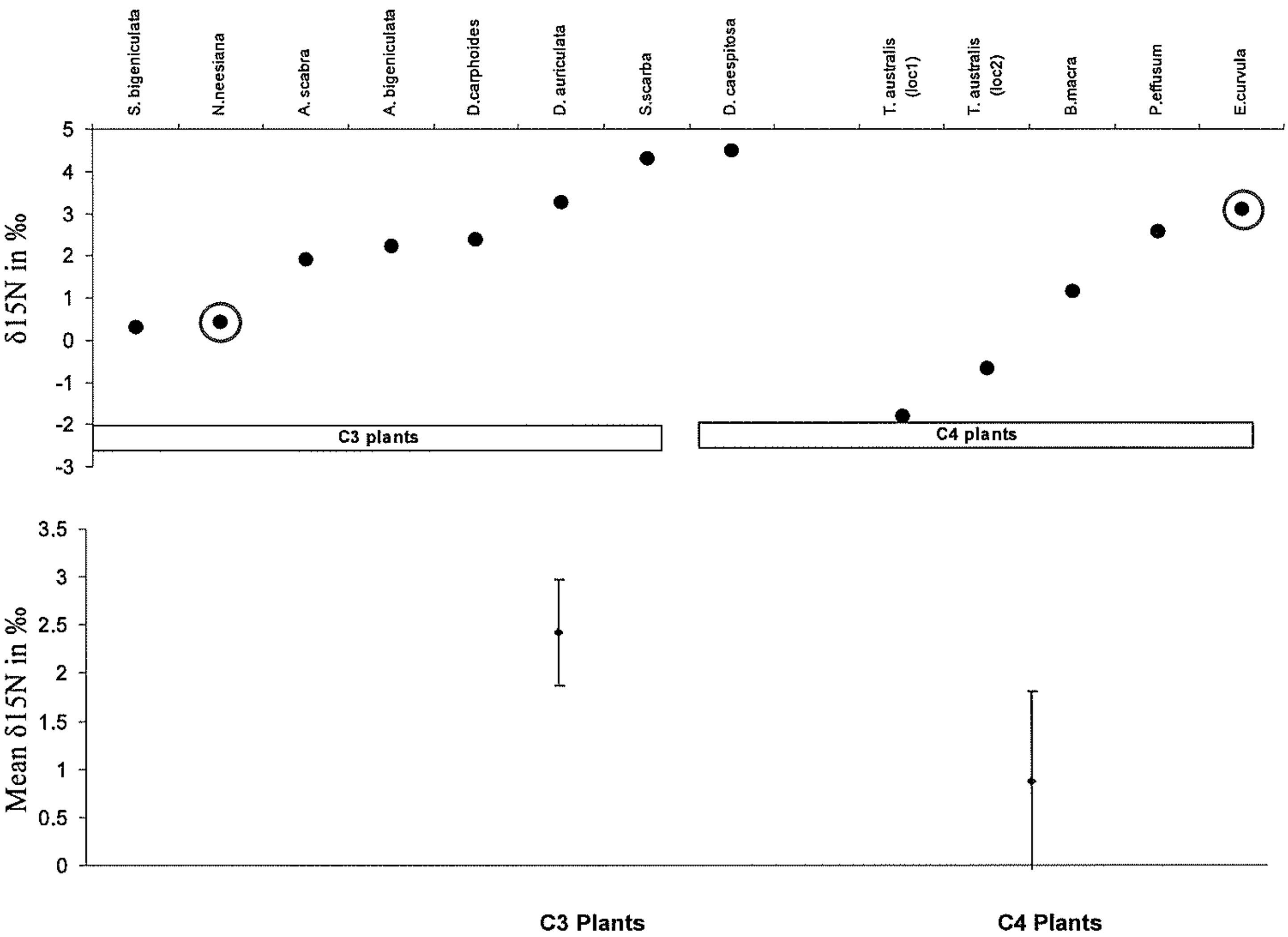


Figure 16 Delta (δ)^{15}N signatures of C3 and C4 grasses commonly associated with habitats of the Golden Sun Moth (upper panel). Red circles indicate exotic plant species. The lower panel figure presents the mean delta 15 N values for C3 (n=8) and C4 (n=5) plants with standard deviation.

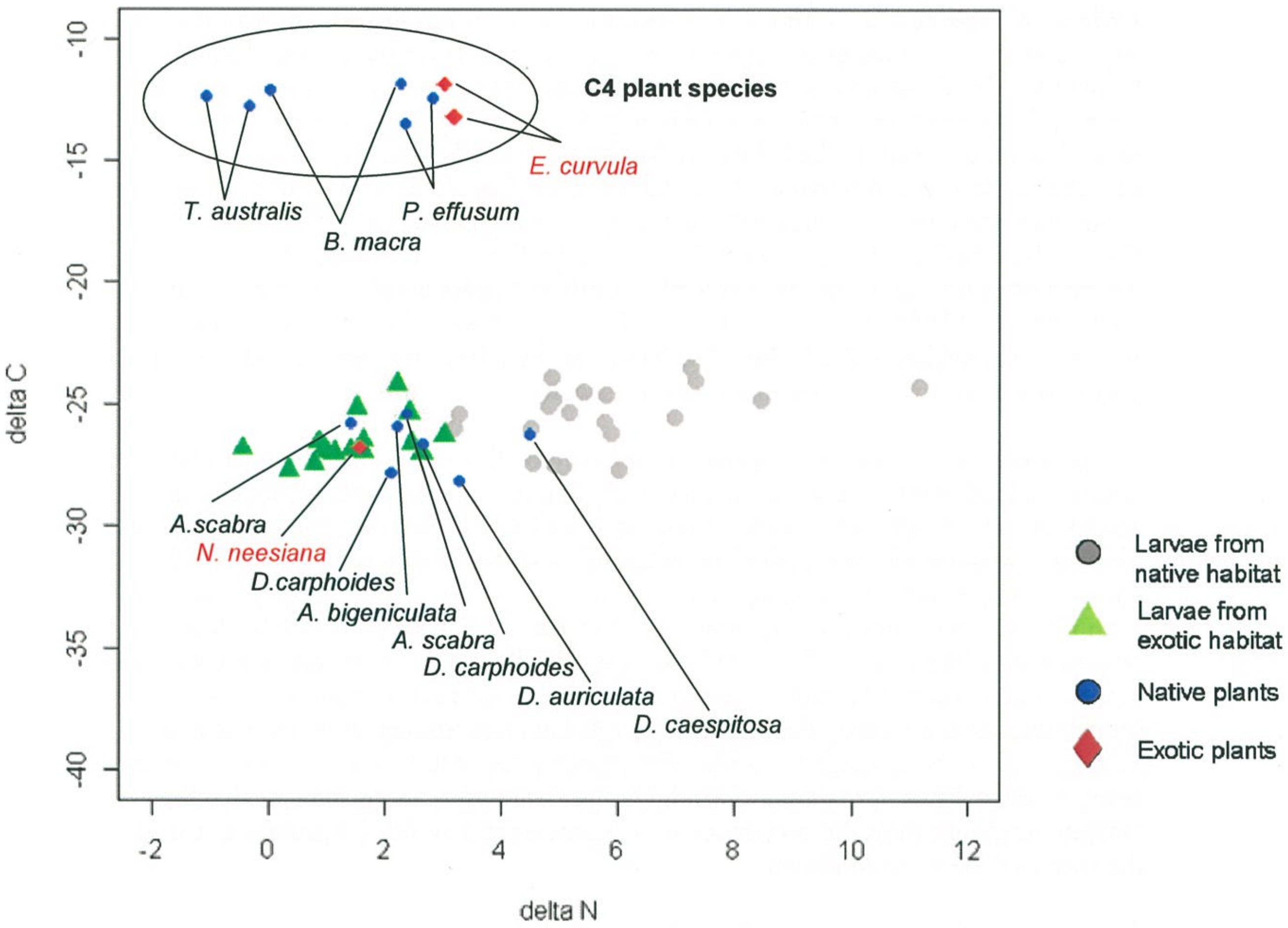


Figure 17 Relationship between delta (δ)[15]N signatures and delta (δ)[13]C signature in Golden Sun Moth larvae obtained from habitats dominated by native (green triangular symbols) and exotic plants (grey circles). Figure illustrates the distinction between C3 and C4 plants (circle around C4 plants) based on higher delta C values. Figure also presents plant species consumed by larvae of Golden Sun Moth based on the isotopic signatures of plant species found in Golden Sun Moth larvae.

DISCUSSION

Our research has revealed that the Golden Sun Moth is not restricted to feeding on a single species of host plant. This confirms the suspicion by several field workers (e.g. A. Richter, W. Osborne, D. Gilmore, V. McKenzie, A. Yen) that the species may feed on species other than in the genus *Austrodanthonia*. Moreover we have found that all Golden Sun Moth larvae tested for their diet preference consumed C3 grasses (grasses with a C3 photosynthetic pathway), including one exotic C3 grass species. Genera of grass that were present in the habitat of the Golden Sun Moth and that were also detected in the isotopic signature of the larvae of the Golden Sun Moth were *Austrodanthonia* (wallaby grasses), *Austrostipa* (spear grasses) as well as the exotic Chilean Needle Grass (*N. nessiana*). From these findings we concluded that *Austrodanthonia* and *Austrostipa* as well as Chilean Needle grass are part of the diet in the Golden Sun Moth. However, other C3 species (grasses and forbs) that are also present in the habitat of the Golden Sun Moth, and that have not been tested, may also play a role in the dietary consumption of the species.

At this stage, our results are not extensive enough to allow us to exclude other plant species as food plants. It does seem very likely that native and exotic plants that are classified as C4 plants are excluded from the diet of the Golden Sun Moth. The species appears to avoid grass swards that comprise only C4 species (for example areas of Kangaroo Grass and areas dominated by the invasive African Love Grass (*E. curvula*) even if these sites abut occupied habitat (A. Richter and W. Osborne unpublished observations). The results of the stable isotope analysis showed that common C4 grasses at the collection sites (African Lovegrass (*Eragrostis curvula*), Kangaroo Grass (*Themeda australis*), Hairy Panic (*Panicum effusum*) and Redleg Grass (*Botrichloa macra*)) were not consumed by larvae of the Golden Sun Moth and therefore are most likely avoided. Thus our laboratory findings and field observations indicate that the Golden Sun Moth show are preference for C3 grasses and avoids C4 grasses as part of the species dietary consumption.

This tendency for an avoidance of C4 plants over C3 plants in herbivorous insects was first hypothesised by Caswell et al (1973). Based on a literature review, Caswell et al (1973) argued that C3 plants are more palatable than C4 plants because of a number of physiological, anatomical and nutritional differences. The cool season plants (C3 plants) are often higher in nutrient content than the warm season plants (C4 plants) with C4 grasses containing less protein and water but more fibre and silica than C3 species (Caswell et al. 1973; Van Soest 1982). Caswell and Reed (1975) showed that the grasshopper, *Melanuplus confuses*, was unable to digest C4 grasses owning to the thick walled bundle sheath cells in C4 grasses and fed exclusively on C3 grasses. Additional research on ten other grasshopper species also indicated that the large quantities of nutritional material in the bundle sheath cell of C4 plants was at least partially unavailable for insect species (Caswell and Reed 1976). Recent research on the hypothesis that plants possessing the C4 photosynthetic pathway are poorer food resources for herbivorous insect than C3 plants has been conducted by Scheirs et al.

(2001). Two species of oligophagous dipteran were tested for their host preference using multiple-choice experiments between four C_3 and four C_4 grasses, two-choice experiments between combinations of C_3 and C_4 grasses, and no-choice experiments (Scheirs *et al.* 2001). The experiments showed a clear feeding and oviposition preference for C_3 grasses for both species. Feeding and oviposition were very rare to absent on all C_4 grasses (Scheirs *et al.* 2001), and this avoidance was explained by these authors as being due to the significantly lower soluble carbohydrate content of C_4 grasses as well as by the "physical-constraint hypothesis" . This hypothesis postulates that the C4 avoidance in herbivorous insects is imposed by a smaller interveinal distance in C_4 grasses which strongly influences the feeding and oviposition pattern (Scheirs *et al.* 2001). Further field observation and experimental research is needed to confirm the extent of any preference for oviposition on C3 plants and C4 plants. Ideally this would take the form of multiple choice experiments.

With respect to the nitrogen signatures in larvae of Golden Sun Moth, our analysis showed increased $\delta 15N$ in larvae from native grasslands. Possible explanations for this finding are 1) a lower quality of food sources in native grasslands leading to starvation effects in the larvae (see below), and 2) higher nitrogen concentrations in the soil that may result from localized variation in soil fertility and/or management. Increasing levels of 15 N concentrations were shown in experiments on insects that were kept without food or had only access to low quality food (Adams and Sterner, 2000; Haubert et al., 2005; Scrimgeour et al., 1995). This isotopic enrichment of 15N is explained with nutritional stress and occurs in situations where available nitrogen decreases and organisms are forced to rely more heavily on internal nitrogenous resources. As indicated by Adams and Sterner (2000 page 5) isotopic enrichment associated with the nutritional stress of limited nitrogen availability may overshadow any increased isotopic enrichment associated with increased nutrient assimilation in the presence of excess nitrogen, thereby causing increased organismal delta 15N values with decreased nitrogen availability. With respect to the Golden Sun Moth, explanations for the higher nitrogen concentrations in larvae collected in native grasslands remain speculative. More research needs to be conducted to identify the reasons for the higher nitrogen concentrations in the larvae of Golden Sun Moth than those of individuals collected from exotic grassland. Rearing experiments with larvae maintained under natural and laboratory conditions would be one possible approach to examining this physiological relationship (i.e. larvae growth and nutrients; quality of food sources).

We consider that our findings about the feeding preference of C3 plants in the Golden Sun Moth are of relevance to the future conservation of this endangered species, particularly in the context of the predicted changes in the Australian climate. Current climate scenarios predict a doubling of levels of atmospheric CO2 (Murphy et al. 2004) with consequent increases in plant biomass and non-structural carbohydrates but decreasing protein (nitrogen) concentrations in leaves (Levis et al. 2000). Changes in CO2 concentrations are expected to lead to a greater decline of nutritional quality in C3 plants following a predicted increase in feeding damage on C3 plants to a greater extent than on C4 plants through herbivorous insects (Lincoln et al.1984). These changes will directly affect the availability of C3 plants as host plants for herbivorous insects as a result of changes in the distribution and abundance of C3 plants. Less mobile groups, such as invertebrates will be affected particularly by this change. It is expected that the Golden Sun Moth will be highly vulnerable to the effects of climate change if there is trend towards C4 plants replacing C3 plants. In the context of climate change, the finding about the use of Chilean needle grass by Golden Sun Moths will need further research to understand the role of this exotic C3 plants as potential host plants for herbivorous species.

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APPENDIX

List of grass and plant species tested for their delta $(\delta)^{13}C$ signatures as outlined in Figure 15.

Number	*Scientific name*	*Common name*
1	Hypochaeris glabra	Smooth cat's ear
2	Echium plantagineum	Paterson curse
3	Erodium crinitum	Blue herons bill
4	Daucus glochidiatus	Native carrot
5	Danthonia auriculata	Lobed Wallaby Grass
6	Carthamus lanatus	Saffron Thistle
7	Triptilodiscus pygmaeus	Austral sunray
8	Euchiton sphaericus	Creeping Cudweed
9	Chrysocephalum apiculatum	Common Everasting
10	Linaria arvensis	Corn Toadflax
11	Trifolium arvense	Haresfood clover
12	Danthonia carphoides	Short Wallaby Grass
13	Nassella neesiana	Chilean Needle Grass
14	Danthonia auriculata	Lobed Wallaby Grass
15	Bromus mollis	Soft Brome
16	Austrostipa scabra	Rough spear grass
17	Austrostipa bigeniculata	Kneed Spear-grass
18	Poa sieberana	Snow Poa
19	Nassella neesiana	Chilean Needle Grass
20	Danthonia carphoides	Short Wallaby Grass
21	Danthonia caespitosa	Common Wallaby Grass
22	Danthonia caespitosa	Common Wallaby Grass
23	Deyeuxia quadriseta	Reed Bent-grass
24	Austrostipa scabra	Rough spear grass
25	Austrostipa bigeniculata	Kneed Spear-grass
26	Austrostipa bigeniculata	Kneed Spear-grass
27	Austrostipa scabra	Rough spear grass
28	Austrostipa bigeniculata	Kneed Spear-grass
29	Austrostipa scabra	Rough spear grass
30	Panicum effusum	Hairy Panic
31	Eragrostis curvula	African Lovegrass
32	Themeda australis	Kangaroo Grass
33	Themeda australis	Kangaroo Grass
34	Panicum effusum	Hairy Panic
35	Panicum effusum	Hairy Panic
36	Themeda australis	Kangaroo Grass
37	Bothriochloa macra	Red-leg Grass
38	Bothriochloa macra	Red-leg Grass
39	Eragrostis curvula	African Lovegrass

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ORIGINAL PAPER

More than an empty case: a non invasive technique for monitoring the Australian critically endangered golden sun moth, *Synemon plana* (Lepidoptera: Castniidae)

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Abstract Monitoring programs for butterflies and moths are focused on the adult stage, rarely considering other life stages. Transect-based counts of adults and searches for empty pupal cases have been suggested as standard monitoring protocols for the critically endangered golden sun moth *Synemon plana* in Australia. To date, surveys and monitoring have focused only on counts of adults. However, undertaking such counts is constrained by the short adult life of the species (1–2 days), and the fact that prevailing weather conditions can seriously influence detectability. We tested whether empty pupal cases of *S. plana* can be used to supplement the monitoring of adults and whether this technique can be undertaken by citizen scientists. Volunteers from Canberra (Australia) collected 650 pupal cases from 11 grassland areas. The cases were found in native grasslands and in grassland comprised entirely of the exotic Chilean needle grass (*Nassella neesiana*). Pupal cases of *S. plana* were found to be durable, with most persisting in the field for greater than 3 weeks after first sighting, and exhibited a male biased sex ratio. This study demonstrates that detection of empty pupal cases provides a potential additional tool to monitor *S. plana* that is not dependent on the restrictions of prevailing weather conditions and time of day, and can be undertaken by citizen scientists.

Keywords Golden sun moth · *Synemon plana* · Monitoring · Pupal cases · Sex ratio · Citizen scientists

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Introduction

Monitoring is a powerful tool in conservation biology because it provides a measure of population characteristics (e.g. relative abundance, demographic characteristics) that can be collected over time and used to determine relationships with environmental factors such as climate, land use, fragmentation, harvesting and management (Lindenmayer and Likens 2010; Spellerberg 2005). Butterflies and moths are highly suited as environmental indicators and have attracted considerable public interest as groups suitable for long term monitoring (Van Swaay et al. 2008). For example, information derived from European butterfly monitoring programs over the past 30 years have provided evidence of a significant decline in many species, and evidence of an extension of the range of some species, principally towards northerly latitudes (Asher et al. 2011; Van Swaay et al. 2008). The application of monitoring data has led to improved conservation practices in many countries and this has halted the decline of some species (Asher et al. 2011; Brereton et al. 2011). Although changes in methods can confound the interpretation of results derived from monitoring programs, such programs are often not static and may be modified to improve statistical power or to improve the efficiency of the techniques used (Lindenmayer and Likens 2010). For example, low population numbers can lead to insufficient data, particularly for rare and endangered species. Species specific characteristics

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such as high mobility or cryptic behavior can constrain the detectability of species and consequently lead to bias towards the more obvious and common species (VanStrien et al. 1997). Prevailing weather conditions are often not suitable for monitoring weather sensitive groups, such as butterflies and moths, and this presents a challenge to volunteers and professionals.

Butterfly and moth monitoring programs conducted with the assistance of citizen scientists generally focus on the adult stage. This is because monitoring adult life forms is typically more appealing to volunteers than recording non adult life forms (Nowicki et al. 2008; Van Swaay et al. 2008). Monitoring non adult stages is potentially of considerable importance for species with very short flight phenologies or for species that are difficult to detect. Monitoring of larvae is a key component of the monitoring program for the iconic monarch butterfly (*Danaus plexippus)* in North America (Garland and Davis 2002; Gibbs et al. 2006) and for lycaenid and fritillary butterflies in Europe (Maes et al. 2004; Konvicka et al. 2005). In Australia, where there are few established monitoring programs for Lepidopterans, several programs include the monitoring of non adult life forms (New 2010). For example, long-term monitoring of the Eltham Copper Butterfly (*Paralucia pyrodiscus lucida*) has included nocturnal counts of larvae (Braby et al. 1999; see New 2010 for review). Also, monitoring activities for the Australian threatened Richmond Birdwing (*Ornithoptera richmondia)* include recording larvae and pupae (Sands 2008). Searches for pupal cases have been recommended as one component of surveys for the critically endangered golden sun moth (*S. plana)* (Australian Government 2009). If non adult forms of *S. plana* can be cost-effectively measured by citizen scientists, then the inclusion of these alternative life forms in monitoring programs will provide valuable information. To examine this possibility we tested whether the collection of pupal cases of the golden sun moth (*S. plana*) can be used as a supplement to the adult surveys. Furthermore, we assessed if this approach can be conducted with the assistance of citizen scientists. To do this we trained volunteers to systematically collect the pupal cases at selected sites in the Canberra region (Richter et al. 2009). We also examined the survival of the pupal cases when left in situ in the field and used those that were collected to determine the sex-ratio of the species at emergence.

The study species

The golden sun moth is listed as critically endangered nationally under the Commonwealth Environment Protection and Biodiversity Conservation Act (1999) (from 2002) and listed as threatened in Victoria (Flora and Fauna Guarantee Act 1998), endangered in the Australian Capital Territory (Nature Conservation Act 1980, listed in 2006) and endangered in New South Wales (Threatened Species Conservation Act 1995; listed in 1996). The original natural habitat of the species in south-eastern Australia is lowland natural temperate grassland, an ecological community that occurs in a naturally treeless landscape often located in frost hollows and on open plains. Sites supporting the moth are characterised by the presence of native grasses including species of *Austrodanthonia* (Edwards 1994). Since European settlement more then 95 % of these grasslands have been destroyed or highly modified as a result of agricultural, rural and urban development (Kirkpatrick et al. 1995). *Synemon plana* is likely to have been widely distributed across these native grasslands at the time of European settlement (Clarke and Whyte 2003), but now has been largely extirpated throughout its former range (Braby and Dunford 2006; Clarke and O'Dwyer 2000). When our study commenced in 2007 the species was known from 125 sites (records post 1990) across a potential range of more than two million hectares. Recent surveys in Victoria have almost doubled the number of known sites (Brown et al. 2012). Most of the grassland sites where the species has been recorded are smaller than five hectares and face ongoing pressures from rapid urban and rural expansion and degradation (Braby and Dunford 2006; Gibson and New 2007; Gilmore et al. 2008).

The adults are diurnal and have a flight season between mid October and early January (spring to summer), depending on local climate and topography. The species is only active during the hottest part of the day (1000–1500 hours) (possibly up to 1700 hours for females) on sunny and cloudless days with a low to moderate wind speed. Temperatures can reach 37 degrees Celsius during these conditions. In the field, adult golden sun moths typically live for 1–2 days (Richter 2010) and lack functional mouthparts for feeding or ingesting any liquid. Females are rarely observed to fly, and when they do the distances traveled in a single flight are typically in the order of a few metres (up to 20 m), whereas males have been observed to fly for several hundred metres. Males fly in a zigzag pattern above the grass sward to search for receptive females; the females remain on the ground and display their bright orange hind wings to attract males. Immediately after mating females crawl quickly amongst the grass tussocks and lay between 80 and 100 eggs at the base of native grass tussocks (Edwards 1994). Based on our observations of oviposition, the eggs are not clumped but appear to be spread over many tussocks. Larvae are thought to emerge about 20 days after laying and feed on the bases of the culms and roots of native grasses (Edwards 1993). Based on the size classes of larvae encountered in the soil it appears that they remain underground for at least 2 years

(Edwards 1994). Pupation occurs in spring. The larvae prepare a burrow (feeding tube) that leads to the soil surface and move to the ground surface where they pupate and emerge. Following adult emergence the pupal shells are left partially protruding above the surface or fully exposed. Pupal cases can be readily found by searching through and around the shorter tussocks and inter-tussock spaces (Richter et al. 2009).

The presence of *S. plana* populations and their pupal cases in natural temperate grassland dominated by *Austrodanthonia* has led to the assumption that the species is a dietary specialist, feeding only on selected species in this genus (most notably *Austrodanthonia carphoides*) (Edwards 1993). Recently, several *S. plana* populations have been recorded at sites dominated by the exotic grass Chilean needle grass (*Nassella neesiana*) (Braby and Dunford 2006; Gilmore et al. 2008) but the suitability of this grass as a component of the diet of the moths needs further investigation. Chilean needle grass is native to South America, was introduced to Melbourne, Australia in 1934 and from there has spread into many locations throughout Australia. It is widespread in parts of the cities of Melbourne and Canberra and was declared a Weed of National Significance in Australia (Anonymous 1999). The assessment of the current distribution of *S. plana* in native and Chilean needle grass dominated grasslands has been constrained by: (1) the bias in counts of adult *S. plana* towards males because of their more conspicuous flight behavior; (2) the difficulty of collecting data due to the restricted time that adult surveys can be conducted because of frequent unsuitable weather; (3) the difficulty of collecting data from several populations at the same time because of the short daily activity period; and (4) the fact that an absence of adult moths can only be inferred if observations are made under ideal weather conditions. Furthermore, the lack of tested monitoring methods exacerbates comparative analysis.

Methods

The study was undertaken between September 2007 and April 2008 in and near Canberra, Australia. The research was conducted with the help of volunteer citizen scientists participating in the 'Sun Moth Count' project coordinated by the Institute for Applied Ecology at the University of Canberra (Richter et al. 2009). More than 50 members of the community took part in workshops, training sessions and the on-site monitoring program. Four workshops of more than 6 h each and three field training sessions were held to introduce the participants to monitoring techniques for *S. plana*. On-site guidance was provided to volunteers throughout the project. Each volunteer was assigned to a particular grassland site. The 11 survey locations were grouped into native grassland sites (grassland dominated by native grasses e.g. *Austrodanthonia* spp, *Austrostipa* spp and forbs) and exotic grasslands (in this case grassland entirely dominated by the invasive Chilean Needle grass [*N. neesiana*)]. For each location we prepared a digital map that showed the specific positions where 12 randomly selected 1 m^2 survey plots were to be placed. Each plot was visited four times (no closer together than 1 week) before the survey was considered to be finished. During each visit we asked the participants to search for, and collect, all empty *S. plana* pupal cases found in the survey plots. To prevent damage to the cases they were often removed with the soil and silk webbing that was attached to them. These were later cleaned and sexed by comparison with a reference collection of male and female pupal cases. The total length of each case was also measured with digital calipers.

At one representative site in natural temperate grassland in the suburb of Belconnen (former Belconnen Naval Station), 31 *S. plana* pupal cases were left in situ and their locations individually marked with flags. These cases were examined from 7 November 2008 to 12 January 2009 to estimate their durability under natural conditions (degradation by wind or rain action or trampling by kangaroos). Daily weather conditions (rainfall and temperature) during the study were derived from data provided by the Bureau of Meteorology for the nearest weather station at Mitchell (3.5 km away). For the analysis of the durability of the pupal cases we used the program MARK to calculate the survival probability (phi) for an open population (assemblage of pupal cases) where birth (emergences of new cases) and death (degradation of cases) can occur. One-way and two-way factorial analysis of variance (ANOVA) using generalized linear models (GLM SPSS) were used to test for significant differences in sex ratios among types of grassland and in sizes of pupal cases.

Results

A total of 650 pupal cases were collected of which 479 were obtained from eight locations in native temperate grassland (NTG) and 171 from three locations in grasslands that were dominated by the exotic Chilean needle grass (CNG). Less than 2 % of all pupal cases collected by the citizen scientists had been misidentified. The mean female pupal case length was 23.15 mm ($n = 145$, 0.18 SE) whereas the mean male pupal case length was 21.66 mm ($n = 238$, 0.24 SE) and these differences were significant ($F = 11.451$, $df = 1{,}377$, $p = 0.001$). Cases collected from exotic grassland (Chilean needle grass) were significantly larger than cases collected in natural temperate grassland ($F = 30.299$, $df = 2.377$, $p = 0.000$). The ratio of males to females in *S. plana* populations in natural temperate grassland was found to vary between 0.6 and 3.5

with a mean 1.9 sex ratio (Table 1). Also, nearly twice as many *S. plana* males than females were found at sites dominated by Chilean needle grass (Table 1). The sex ratio bias towards males did not vary between the 2 years studied (Fig. 1). The survival analysis performed in program MARK (version 5.1) on 31 empty pupal cases showed that *S. plana* pupal cases had a high “survival” rate (phi = 0.9–1.0) between one and 24 days after marking (Fig. 2). A large proportion of the empty cases (95 %) could still be found after 24 days, and this was after an extreme rainfall event on 13 November 2008 when 60 mm of rain were recorded (Table 2). Their detectability decreased after 24 days, and after more than 40 days < 50 % of *S. plana* cases were still present and identifiable in the field. At the last visit to check for the presence of empty cases 50 days after initial marking, all cases had degraded.

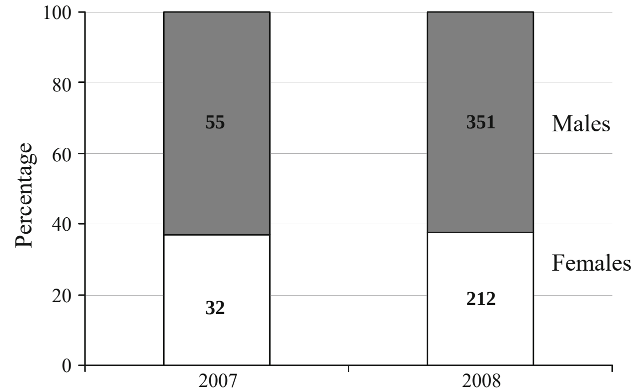

Fig. 1 Sex ratio in *S. plana* populations based on pupal case identification from samples (n = 650) obtained in 2007 and 2008 in native temperate grassland and exotic grassland dominated by Chilean needle grass (*N. neesiana*). Males are indicated by *shaded bars*, females by *open bars*. The number of specimens examined in each year is listed within the *bars*

Discussion

The survey and monitoring guidelines for *S. plana* recommend fixed point (or “spot count”) and transect surveys as standard tools for the detection of adult *S. plana* (DEWHA 2009). The guidelines also recommend the use of pupal case surveys, however the usefulness of this as an alternative monitoring tool has not been assessed and we are not aware of anyone employing this approach. Our findings indicate that searches for empty pupal cases can provide a potential additional tool for monitoring *S. plana* populations that is not dependent on prevailing weather conditions and time of day. We demonstrated that monitoring empty pupal cases can be undertaken readily by citizen scientists (trained volunteers) and that examination

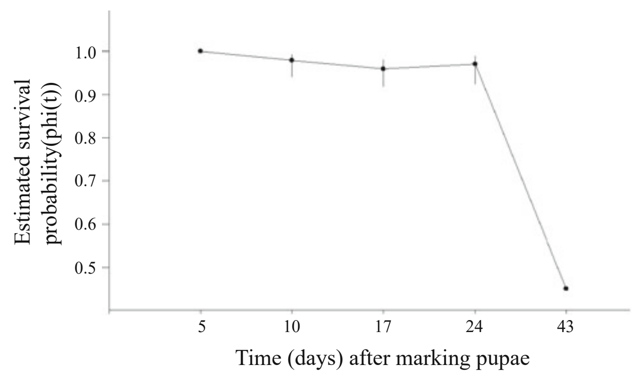

Fig. 2 Pupal case durability under natural conditions based on the survival probability analysis [phi(t)] between 07.11.2008 and 12.01.2009 at one of the largest natural temperate grasslands in the ACT (former Belconnen Naval Transmitting Station). *Bars* indicate standard error

Table 1 Sex ratio variations in *S. plana* pupal cases (exuviae) collected from Chilean needle grass sites (A–C) and native grassland sites (1–8) in the Australian Capital Territory (ACT)

Site	Vegetation classification	Male: female	Sample size
A	CNG	2.5	14
B	CNG	2.1	114
C	CNG	1.9	43
1	NTG	3.5	9
2	NTG	2.5	14
3	NTG	2.4	111
4	NTG	1.8	91
5	NTG	1.3	7
6	NTG	1.3	214
7	NTG	0.6	8
8	NTG	0.6	25

of the cases provides information about the occurrence of the species and additional biological information.

Most international monitoring programs for butterflies and moths focus on recording the presence and abundance of adults. Recording the response of other life stages to changing environments has received less attention (Nowicki et al. 2008). This bias is not surprising given that most species are easily recognised as adults, and in many countries the biology and ecology of most species are reasonably well documented. This has allowed for the development of reliable approaches to monitoring. Despite the appeal of focusing on the adult life stage, most species of insects spend the greater part of their life either as an egg, larva or pupa. It is obvious that climate change, habitat destruction and inappropriate management will also impact on individuals at these early life stages (Smart et al. 2000; WallisDeVries et al. 2011). Therefore, documentation of

Table 2 Total rainfall (mm) and average maximal temperature (grad Celsius) occurring during the test of durability of empty pupal cases

Rainfall (past 24 h)			mm
13 Nov 2008			62.2
18 Nov 2008			6.2
23 Nov 2008			1.4
24 Nov 2008			4.4
28 Nov 2008			24.6
Average max temperature (past 24 h)	**Celsius**	**Min.**	**Max.**
07 Nov–30 Nov 2008	23.9	13	28.9
01 Dec–31 Dec 2008	25.4	19.8	30.7
01 Jan–12 Jan 2009	28.5	21.9	36.5

the responses of particular environmental perturbations to non-adult life forms is also relevant for the assessment of their conservation status. Unfortunately, the comparative ease of working with adult butterflies and moths has factored against the development of techniques for non-adult life stages. Nevertheless, for species with very short adult phenology or for species where the detection of adults is difficult (e.g. cryptic behaviour, flying high in trees), the identification of egg, larval or pupal cases can be straightforward and even in some cases advantageous over the identification of the adults (Doerpinghaus et al. 2005; Hermann 1999; Lewis and Hurford 1997).

We have demonstrated that counts of pupal cases of *S. plana* can be used as a valuable tool for monitoring local populations. The practical factors that enhance the value of this approach include the following. First, since individual adult golden sun moths only survive for a day or two, observations of the adults can vary considerably from day to day. Such variation should not be present when pupal cases are counted (unless the site is disturbed in some way during the census period). If the counts are directed towards the end of the flight season then we expect that they will provide a reasonable estimate of accumulated population density for the entire season. By counting on multiple plots, it should be possible to calculate a mean value for emergence density of moths in that season, allowing for comparison with other sites. Second, the monitoring of pupal cases is independent of the species flight season. We demonstrated that pupal cases of *S. plana* are still present and identifiable under natural conditions 3 weeks after first detection (Fig. 2). In fact, the pupal cases 'survived' several days of high temperatures, rainfall and trampling from herbivores (kangaroos) (Table 2). By contrast, adults can be difficult to detect because of their short period of daily activity, the narrow range of suitable weather conditions that enable emergence and flight and their short life span. Thus, the monitoring of the presence and density of adult *S. plana* can be supplemented by the documentation of the presence and density of empty pupal cases. Our study demonstrates that monitoring that is based on counting pupal cases can start after the first emergence of adults and can continue until beyond the end of the flight period. The durability of pupal cases should be considered when establishing a suitable interval between counts. An overestimation of the density of the moth through multiple counts of the same cases can be avoided by marking them with paint or removing the cases. At this stage, however, the relationship between the total population of adults that have emerged by a given date and the accumulated total number of pupal cases that can be found is not known and requires further research. We note that most grassland sites surveyed during our study were characterised by short vegetation as a result of severe drought conditions. Therefore, a possible limitation of the approach is that it might be difficult to find and count the pupal cases in situations where the grass is taller—such as might occur during wetter growing seasons. Finally we note and agree with the caution given by New (2012) that the immature stages of *S. plana* have not been formally described and that specialists are required for correct identification. This consideration needs to be factored into any surveys that are based on counts of pupal cases.

Monitoring programs document trends in the distribution of species but also provide valuable information about the biology and ecology of the species. Many butterfly species live in close association with plants (host plant relationship) and interact with other animals (e.g. ants) (New 1993). Thus, the observation of eggs and larvae on host plants, and any records of interactions with other taxa (e.g. larvae being fed by ants); indicate a well functioning relationship between butterfly and moth species and their environment. This information can be used as a supplement for the assessment of the species conservation status at a local scale.

Our study has provided the first record of the sex ratio of emerging adult *S. plana* (based on the sex of pupal cases). The fact that the ratio of reproductive males to females differed from parity in both native and exotic grassland habitats was unexpected. Generally, the operational sex ratio (OSR) is a central life history parameter that affects the population's growth rate and determines the strength of sexual selection through competition for access to mates of the minority sex (Emlen and Oring 1977). When reared in captivity, most species of lepidopterans have an unbiased primary sex ratio (offspring sex ratio at the time of conception) regardless of their sex determining system (Ehrlich et al. 1984). However, it has been observed that some species of butterflies exhibit variable sex ratios under natural conditions (Dyson and Hurst 2004). Deviation from parity is likely to be corrected through frequency dependent selection, which acts to equalize parental investment in the two sexes (Fisher 1930). Such adjustment arises through the fitness advantage incurred by the individuals that are genetically predisposed to bias their brood towards the minority sex, which in turn are more likely to encounter a mate than members of the majority sex and therefore provide a higher reproductive return and fitness gain to their parents. We detected a distinctive male-biased sex ratio in *S. plana* populations that was consistent across 2 years and did not differ significantly between native grassland and exotic *N. neesiana* grassland (Fig. 2). The factors that are likely to maintain a male bias in *S. plana* populations are unknown at this stage. To further understand the conditions that facilitate such dynamics, both physiological and ecological parameters of the species life history must be considered. For instance, sex determination might be influenced by environmental factors such as egg incubation temperature, which in turn could account for some or all of the observed bias. Species that produce a male bias are common, but so are those that produce equal sex ratios or only female offspring (Adamski 2004; Jiggins et al. 1998). The underlying causes of such variations in the primary sex ratios are unknown but suggested causes for this have included maternal inheritance (Jiggins et al. 1998), biased predation as a consequence of sexual dimorphism (Bhattacharya 2004), sex-biased differences in microhabitat selection, and differences in "catchability" or lags in emergence times of females relative to males (protandry) (Ehrlich et al. 1984; Frey and Leong 1993). In the case of adult *S. plana*, males and females differ significantly in their morphology and behavior. Males are less brightly-coloured and are much more competent flyers (Edwards 1994). By contrast, females are very cryptic and extremely poor dispersers (Edwards 1994). Females only display their bright orange hindwings to indicate their courtship solicitation during a very small fraction of their lifespans. Most of the time females are inactive (when males are patrolling) or are assiduous with the deposition of eggs; mainly during the afternoon when male activity has ceased. Also, adult male moths have been observed to be prey for robber flies (Asilidae family) and birds (Clarke and O'Dwyer 2000). Thus, adult males and females differ in their predation risks, catchability and visibility, which will greatly influence any evaluation of the adult sex ratio within populations. The sex ratio of pupal cases suggests that there is a natural bias in adult sex ratio, that somewhat mirrors that of the adults based on transect counts (Richter, personal observation). The occurrence in situ of empty lepidopteran pupal cases provided a specific and reliable indicator of habitat use by the species.

The presence of pupal cases in native grasslands and in grasslands that are comprised entirely of the exotic Chilean needle grass supports the view that this endemic Australian species has expanded its range to include these exotic grasslands. However, the presence of pupal cases at sites that appear to be comprised entirely of Chilean needle grass does not necessarily indicate that the larvae have fed on the roots of this species. There is some possibility that the moths may have fed on the roots of residual species of native grass that are no longer evident in the grass sward, although this is becoming increasingly less likely as more sites are being found where the species appears to be breeding in Chilean needle grass (Gilmore et al. 2008; Richter et al. 2009; Brown et al. 2012). It is very likely that empty pupal cases can be used in molecular analyses to test for dietary content in *S. plana* [see for examples (Feinstein 2004; Watts et al. 2005)]. Stable isotope analysis is also now a widely used technique for investigating diet, trophic position and ecological function in communities (Post 2002) and, since it has been used with other lepidopteran pupal cases (Tibbets et al. 2008), it could be also used to investigate the feeding strategies in *S. plana.*

In conclusion, it is our view that non invasive sampling of pupal cases provides a valuable source of information about the critically endangered golden sun moth *S. plana*. The surveys can be undertaken readily by citizen scientists, providing an opportunity to contribute to resolving some of the remaining questions about the species conservation status and biology and establishing a much-needed monitoring program for the species. The pupal cases should be considered as being much more than "just an empty case" and hopefully will make an important contribution to future research and monitoring.

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ORIGINAL PAPER

Moths in fragments: insights into the biology and ecology of the Australian endangered golden sun moth *Synemon plana* (Lepidoptera: Castniidae) in natural temperate and exotic grassland remnants

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Abstract The conservation and management of endangered species requires an adequate understanding of their biology and ecology. Although there has been an increasing appreciation in Australia of the need for greater efforts to conserve insects, there is only limited information available that can be used to underpin conservation efforts. The endangered golden sun moth, *Synemon plana* (Lepidoptera: Castniidae) is a flagship species endemic to natural temperate grassland in south-eastern Australia. Most populations of this species are at considerable risk from habitat loss, weed invasion and inadequate management. Despite the considerable knowledge that exists about the species biology and ecology, efforts to improve the species conservation status are hampered because there are still critical gaps in our understanding of the species' natural history. In particular, the ecology of the larvae is not known. Our study examined the abundance, population structure and reproductive biology of the moths in a broad sample of both natural temperate and exotic grassland remnants in and near Canberra in the Australian Capital Territory (ACT) in south-eastern Australia. The results fill critical gaps in the knowledge needed to achieve effective conservation management. From our findings, it is clear that the species inhabits grasslands dominated by a mixture of native wallaby grasses (*Rytidosperma* spp. (formerly *Austrodanthonia*)) and spear grasses (*Austrostipa* spp.). In contrast to earlier suggestions that *S. plana* is entirely confined to natural temperate grassland, mature and immature life stages of the species were also present in grasslands comprised entirely of the exotic Chilean needlegrass (*Nassella neesiana*). Most of the *S. plana* populations surveyed in the ACT were characterised by low relative abundance with only very few large populations being recorded. The conservation of exotic grasslands as substitute habitat for *S. plana* is discussed and suggestions regarding future monitoring and research of the species are provided.

Keywords Golden sun moth · Synemon plana · Chilean needlegrass · Abundance · Conservation · Monitoring

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Introduction

The Australian golden sun moth, *Synemon plana* (Lepidoptera: Castniidae) is an enigmatic day-flying moth that is listed nationally as a Critically Endangered species (Australian Government 2012). The original natural habitat of the species is believed to have been a component of natural temperate grassland in south-eastern Australia, a threatened ecological community that is found in a naturally treeless landscape and characterised by a diverse range of native grasses and forbs, both of which usually reflect a lack of human disturbance. Before European settlement, natural temperate grasslands were distributed patchily throughout the temperate climatic zone in south-eastern Australia, covering more than two million ha (McDougall and Kirkpatrick 1994). Since European settlement more than 95 %

of these grasslands have been lost or highly modified as a result of agricultural, rural and urban development (Kirkpatrick et al. 1995). Remaining natural temperate grasslands are often small in size and highly isolated (Sharp and Shorthouse 1996) and are considered to be endangered communities (Australian Government 2009).

Synemon plana is likely to have been widely distributed across the natural grasslands of South-eastern Australia at the time of European settlement (Clarke and Whyte 2003). Large scale native grassland losses, reductions, degradation and fragmentation have resulted in the local extinction and reduction of *S. plana* populations throughout its former range (Braby and Dunford 2006; Clarke and O'Dwyer 2000). The species is known from 125 sites (post 1990 records) with 48 known sites in NSW, 46 in Victoria and 32 in the ACT (Australian Government 2012; Brown et al. 2012). Most grassland remnants inhabited by *S. plana* are smaller than five hectares and face the ongoing pressures of rapid urban and rural expansion and habitat degradation (Braby and Dunford 2006; Gibson and New 2007; Gilmore et al. 2008). In addition to this large scale loss of habitat, the species has also suffered from site specific disturbances that have led to a loss of host plants, further loss of connectivity and reductions in the size of local populations. The species unusual life history (described below) compounds these difficulties.

Adult *S. plana* emerge from the soil between the end of October and mid January, and have a very short adult life span, typically consisting of only 1 or 2 days post emergence (Cook and Edwards 1993, 1994; Richter 2010). Adults are active only during the hottest part of the day (typically between 11 a.m. and 2 p.m.; and sometimes later) on warm to hot, cloudless and slightly windy days (Edwards 1993, 1994). Males fly rapidly in a zigzag flight pattern about 1 m above the grass sward, searching for females that sit on the ground with their bright orange-marked wings spread to attract males. Females are not often observed flying, although they can fly short distances (usually less than 5 m, but on occasions up to 20 m; author's personal observations). They are more frequently observed perched at ground level or walking rapidly through the grass tussocks as they choose oviposition sites. By contrast, males are very active fliers and are capable of moving distances of several 100 m (authors personal observations). Adult *S. plana* lack functional mouthparts, with feeding being restricted to the larval stage. Current understanding of the likely diet of the species is based on observations of their pupal cases within the basal tussocks of native grass species, particularly wallaby grasses (*Rytidosperma* spp.) and spear grasses (*Austrostipa* spp.), taxa that are the host species (Edwards 1994). Recently the view that *S. plana* is entirely dependent on native grass has been questioned. In both Victoria (Melbourne; Gilmore et al. 2008) and the ACT (Braby and Dunford 2006), populations have been recorded breeding in grasslands comprised almost exclusively of the exotic Chilean needlegrass (*Nassella neesiana*), a South American noxious weed of national significance (Australian Weeds Committee 2012). In the ACT many pupal exuviae have been recorded from within the tussocks of this exotic grass (Braby and Dunford 2006; Richter et al. 2012). In contrast to these studies, Brown et al. (2012) found no infestation of Chilean needlegrass on sites that supported *S. plana* in a targeted field survey of *S. plana* at sites distributed across the Victorian Volcanic Plains.

Since the recognition of *S. plana* as a Critically Endangered species and the listing of its habitat as a Critically Endangered ecological community, the moth has attracted the status of a flagship species for the conservation of natural temperate grassland (ACT Government 2005; DSE 2009). This has led to further research on their biology and distribution (Braby and Dunford 2006; Edwards 1994), habitat requirements and restoration (O'Dwyer and Attiwill 1999, 2000), genetic population structure (Clarke 2000; Clarke and O'Dwyer 2000; Clarke and Whyte 2003) and population dynamics (Gibson and New 2007). Despite this effort, many important components of their biology and ecology, including detailed information about the species habitat specificity, larval biology including diet, and fecundity, remain unknown. In this paper we present the results of a 3-year study that focused on evaluating the demography and habitat specificity of *S. plana* adults in grassland remnants in the ACT. In addition, we examined the population structure of adults and, for the first time, we provide information about the biology of *S. plana* larvae in natural temperate grassland and exotic grasslands invaded by Chilean needlegrass. We also report on the effects of grassland size and floristic composition on the species. Our primary aim was to fill critical gaps in the understanding of the life history of *S. plana* and to describe more precisely the habitat requirements of the species. It is envisaged that this information will lead to a better understanding of the species and its conservation management.

Methods

Study area and sites sampled

The study was undertaken in and around the city of Canberra in the ACT in south-eastern Australia (Fig. 1). Study sites were all located at low elevations (560–620 m) reflecting the occurrence of the species in cold air drainage basins and open treeless plains. The seasons in Canberra are characterised by hot summers (December–February) and cold winters (June–August). The average annual precipitation in Canberra is approximately 630 mm, evenly distributed throughout the year with the wettest month being October and the driest being June (Bureau of Meteorology 2010). The characteristic soils of the tableland plains in the ACT are podzolics and grey and brown clay soils (Gunn et al. 1969) that support floristically diverse communities of annual and perennial native grasses (Sharp 1993). Between 2006 and 2009, 47 grassland sites (36 sites in 2006/07, 45 sites in 2007/2008, 28 sites in 2008/2009), with a combined total of 570 ha, were surveyed for *S. plana*. The sites were evenly distributed throughout the northern lowland areas of the ACT in and near Canberra. Selection of sites was based on previously recorded occurrences of *S. plana* (ACT Government 2005) and the potential suitability of grasslands for the species. The inclusion of exotic and pasture grassland sites, that were previously considered unsuitable for *S. plana*, followed recent sightings of the species in exotic grasslands in the ACT and in Victoria (Braby and Dunford 2006; Gilmore et al. 2008).

Population ecology of adults

Relative and absolute population size

Repeated surveys for *S. plana* were conducted at 36 sites in 2006/2007, 45 sites in 2007/2008 and 47 sites in 2008/2009, from mid-October until the end of January, during the main flight activity of adult *S. plana*. The absence of the species was confirmed if individuals were not found after four site visits of at least 20 min per visit under suitable weather conditions (>25 °C, slight wind, low cloud cover and no rain) between 10:00 and 16:00 (Eastern Daylight Saving Time). At sites with *S. plana* present, we estimated population abundance during the flight period using modified Pollard-Yates transect counts (Pollard and Yates 1993). The modified Pollard-Yates method involved counting moths within each site along a 100 m linear or curved transect. Each transect was observed for a minimum time of 20 min per observation. All flying male adults were counted and grouped into abundance classes as follows: I: no sightings, II (very low–low): 1–50 individuals, III (medium–high): >50–100, IV (very high): >100 individuals. Females were not counted as they are poor fliers and difficult to detect. Only a single count per survey day for each population was performed. We attempted to survey each site as often as possible, with at least three consecutive censuses being conducted during each flight season. Additional surveys of the relative abundance of the species were conducted using modified circular point counts during 2008/2009 as part of a community-based (volunteer) program (Richter et al. 2009). Circular point counts were considered to be more feasible for use by the volunteers than transect counts and therefore were applied in the field. The modified point count involved standing at the census site and turning slowly through 360° (this took approximately 30 s), counting all males seen flying within 15 m of the observer [this is a modification of the approach used by Gibson and New (2007)]. This method obtained a single instantaneous sample that was averaged over four or more subsequent visits to the site to give a measure of relative abundance. Multiple counts were averaged and grouped into abundance classes as outlined for the estimation of abundance classes using the modified Pollard–Yates method.

In addition to the estimation of the relative abundance of golden sun moth populations using visual counts, population size was estimated at a single site in 2006 [York Park (0.4 ha) in central Canberra] by using a mark–release–recapture technique. York Park is the only location in Canberra where the absolute abundance of *S. plana* has been estimated previously (Cook and Edwards 1993, 1994). This site was resurveyed in 2006 and the results compared with similar data collected in 1992/1993 and 1993/1995 by Cook and Edwards (1993, 1994). Adult males were captured and individually marked between 18 November and 19 December 2006 from 10:30 to 12:30 h (Eastern Daylight Saving Time). Moths were captured randomly with 40 cm butterfly nets and marked with a number on the underside of the hindwing, using a quick-drying, xylene-free, metallic ink pen (Artline 999XF Silver). Only males were marked as study permits did not allow for the capture and marking of females. Thus, no information about the adult life span and population size can be provided for female moths.

Diurnal activity pattern

The daily fluctuation of the number of adults was investigated for three populations of *S. plana* in the ACT (Belconnen, Crace and Campbell) in 2008 (12 Nov, 6 Dec and 7 Dec) (and for one population in Victoria (10 Nov). The observer recorded flying adults of *S. plana* between 10 a.m. and 3 p.m. with particular focus on counting flying individuals between 11 a.m. and 2 p.m. in 15 min intervals. The numbers were obtained from circular point counts.

Habitat specificity

Each site surveyed was assigned to a grassland community based on floristic mapping provided by the ACT government (ACT Government 2005). These grassland communities are classified as: (a) natural temperate grassland; (b) native pasture; or (c) exotic grassland. Natural temperate grasslands are dominated by moderately tall

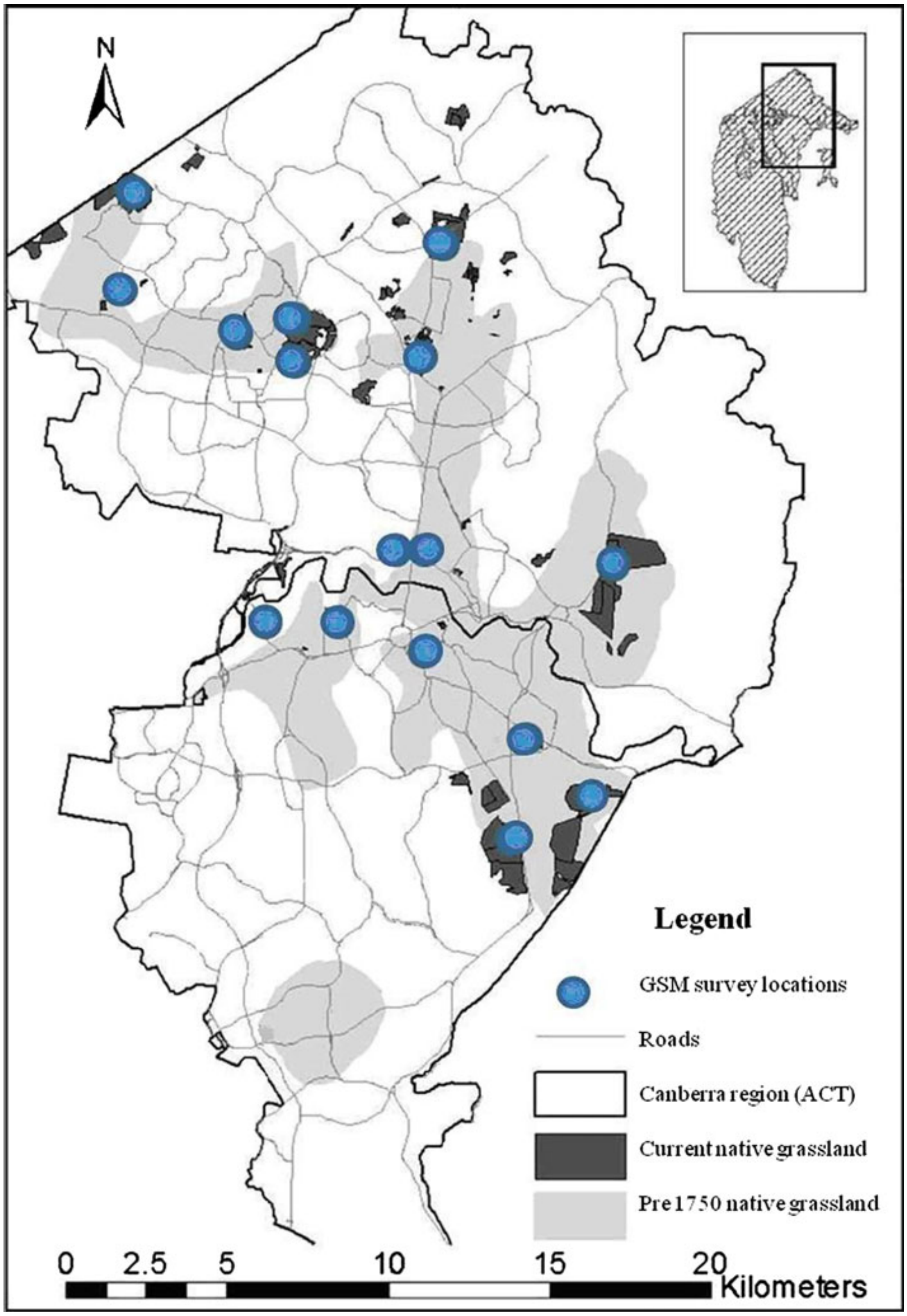

Fig. 1 Map of the north-eastern part of the ACT showing the extent of the Canberra region, the current extent of natural temperate grassland (*dark grey*), the presumed distribution of pre-1750 native grassland (*light grey*), and locations where *S. plana* populations were surveyed (*circles*)

(0.25–0.5 m) to tall (>0.5–1 m), dense to open tussock grasses in the genera *Rytidosperma*, *Austrostipa*, *Bothriochloa*, *Poa* and *Themeda*. Up to 70 % of all plant species in natural temperate grasslands are forbs. Native pastures are defined as a pasture primarily composed of native grasses with a much lower diversity of forb species. Most native pastures have undergone modifications resulting from grazing by domestic stock and in some places the introduction of legumes or fertilisation (Mitchell 2003). Exotic grasslands are characterised by the dominance of species that are introduced to the areas and where all the indigenous vegetation has been removed. Exotic grasslands include improved pastures and cultivated grasslands in agricultural and urban areas (Benson 1996). For our study, the grassland communities were further subdivided as follows: (1) *Austrostipa* (speargrasses), (2) *Rytidosperma* (wallaby grasses), (3) Dry and Wet *Themeda triandra* (kangaroo grass) and (4) *N. neesiana* (Chilean needlegrass; after ACT Government 2005).

Fecundity

Female *S. plana* were caught accidentally in 2006, 2007 and 2008 as by-catches in wet pitfall traps designed to capture terrestrial ground dwelling arthropods (Richter 2010). All females caught were dissected under the microscope and any eggs present were removed individually and counted. Several female specimens showed signs of having laid eggs prior to capture; these specimens were not included in the final analysis. The length (to nearest 0.01 mm) of several hundred single eggs from five different locations was measured under the microscope.

Larval habitats

Habitat specificity of *S. plana* larvae was determined by collecting larvae in late autumn (July) and spring (October) in 2008 at four sites that were known to support large adult populations (hundreds of individuals). Collections were made in two different locations within natural temperate grassland and in two grasslands dominated by the exotic *N. neesiana*. Soil samples that included grass tussocks (approximately $0.2 \times 0.2 \times 0.1$ m) were removed randomly with a small spade and each sample was carefully searched manually for *S. plana* larvae. When any larvae were found, information on their location within the soil, signs of any feeding, and larval morphological characteristics were recorded. Attention was given to detecting signs of larval feeding such as damage to the roots of plants and obvious tunnel systems within the root mass. All species of grass in each soil sample were recorded, and, for larvae still in situ in the soil, the roots of the grass species closest to the larvae were identified by following the root back to the aerial part of the plant. The length and weight of all larvae found were measured in the laboratory. All samples were stored at −80 °C for further molecular analysis. Initial identification of *S. plana* larvae was confirmed by an expert (Ted Edwards, CSIRO Division of Entomology, Canberra) and subsequently by molecular analysis (A. Richter and M. Traugott unpublished data).

Statistical analysis

The capture-recapture data were analysed using open-capture models (Jolly Seber Collmark) in the programs MARK v.4.2 (White and Burnham 1999) and JOLLY. Within MARK, the subprogram POPAN provides a parameterization of the Jolly–Seber model (Schwarz and Arnason 1996) using individual capture histories to estimate population size and variance. This approach generated estimates of the number of adult males in the population over the entire, non-overlapping flight period. A set of a priori models was initially developed, analysed and then ranked by the AIC (Akaike's information criterion) values following analysis in the program MARK. The model with the lowest AIC value was considered the best fitted model and used to analyse N (population size), phi (survival probability) and *p* ((re)capture probability). One-way and two-way factorial analysis (ANOVA) using generalized linear models (GLM) were applied for testing the relationship between habitat use by the species (adults and larvae) in native and exotic grasslands. Statistical tests of marginal homogeneity for variability were performed between abundance classes and years and abundance classes and within vegetation types. Statistics were performed with package R (version 2.9.1).

Results

Populations of *S. plana* were found at 32 of the 47 sites in and near Canberra that were known to previously support the species (Table 1). In addition, the species was found at three new sites surveyed between 2006 and 2009. The dates at which the flight season started and finished and the numbers of days over which adults were active varied from year to year. Active flying male and female moths were

Table 1 Presence and absence of *S. plana* in ACT grasslands characterised by various vegetation types

Vegetation type	No. of sites with *S. plana* absent (%)	No. of sites with *S. plana* present (%)	Total no. of sites
Exotic dominated by Chilean needlegrass (*Nassella neesiana*)	1 (25 %)	3 (75 %)	4
Exotic dominated by Canary grass (*Phalaris aquatica*)	4 (100 %)	0	4
Wallaby grass species (*Rytidosperma* spp.)	2 (8.3 %)	22 (91.7 %)	24
Dry Kangaroo grass (*Themeda triandra*)	3 (75 %)	1 (25 %)	4
Spear grass species (*Austrostipa bigeniculata* & *A. scabra*)	4 (57.1 %)	3 (42.9)	7
Wet Kangaroo grass (*Themeda triandra*)	1 (25 %)	3 (75 %)	4
Total	15	32	47

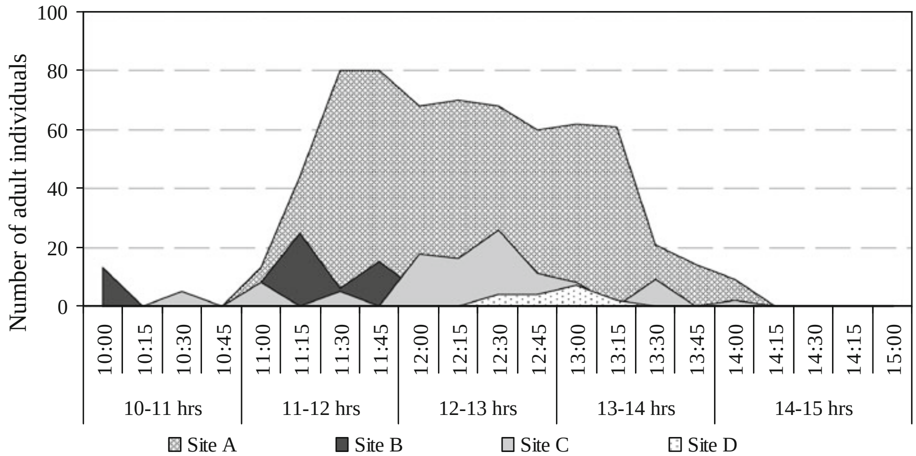

Fig. 2 Daily fluctuations in numbers of male flying golden sun moth adults between 10:00 a.m. and 3:00 p.m. at three sites in the ACT (*A–C*) and one site in Victoria (*D*). *Site A* surveyed 12.11.2008; *site B* surveyed 07.12.2008; *site C* surveyed on 06.12.2008. The Victorian site surveyed on 10.11.2008

detected between 16 October and 27 December in 2006, between mid-October 2007 and 14 January in 2008, and between 29 October 2008 and 13 January in 2009. The highest daily activity pattern in *S. plana* occurred between 10 a.m. and 2 p.m. We recorded several peaks of activity from 10 am onwards separated by periods when the activity was reduced (Fig. 2).

Relative abundance and habitat specificity

The relative abundance of *S. plana* at sites ranged from no sightings to sightings of several hundred individuals (Fig. 3). These proportions remained consistent for individual populations over the 3 years of investigation. Most populations surveyed in the ACT were characterised by few individuals, and at only six sites did our counts number in the hundreds of individuals. The proportion of sites surveyed with no or low numbers of individuals increased from 56 to 70 % between the 2006 and 2009 flight seasons. The actual proportional composition for these abundance classes did not change significantly over the years ($F = 0.122$, $df = 2.62$, $p = 0.885$). Nor did these proportions vary significantly among grassland communities (*Rytidosperma*, Wet *Themeda*, Dry *Themeda*, *Austrostipa*) ($F = 0.174$, $df = 4.31$, $p = 0.950$) or among years within vegetation type ($F = 0.602$, $df = 8.62$, $p = 0.772$). The generalized linear binary regression model showed that the species presence and absence was significantly associated with grassland community ($\chi^2 = 8.286$, $df = 2$, $p = 0.016$). Adult *S. plana* were most likely to be present at sites that were classified as natural temperate grassland compared to those classified as native pasture and exotic grassland (Fig. 4). The presence and absence of *S. plana* was not significantly affected by overall grassland area (fragment size) ($\chi^2 = 1.057$, $df = 1$, $p = 0.304$) nor was presence and absence of the species significantly affected by grassland area (habitat extent) within each vegetation type ($\chi^2 = 0.912$, $df = 5$, $p = 0.340$).

Population size at York Park

In 2006 we captured and marked individually 423 adult male *S. plana* at York Park. Twenty five individuals were recaptured. Survival probability and recapture probability were very low (Table 2). The adult life span of males was on average 1.08 days (±0.119 95 % CI). No moths were captured more than 2 days after marking. The Jolly–Seber

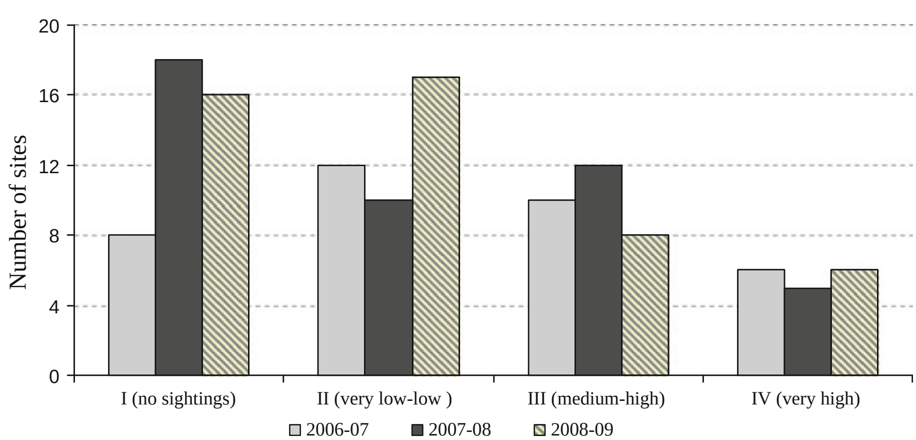

Fig. 3 Relative abundance of *S. plana* at 47 grassland sites in the ACT between 2006 and 2009. Includes both natural temperate and exotic grasslands

model, with both survival rate (phi) and capture probability (p) assumed to be constant per unit time, estimated a mean daily population size of 42 individuals (S.E. 4.20) with ranges from a minimum of nine individuals on 13 December (S.E. 4.73) to a maximum of 66 individuals (S.E. 18.05) on 2 December 2006 (Fig. 5). The best approximating model for open populations used for the analysis for total population size was with a constant parameter for survival and recapture. The total *S. plana* population at York Park in 2006 was estimated to be 440, with a range of 412–520 individuals.

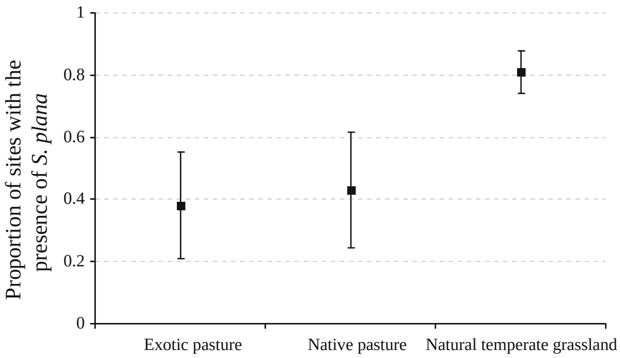

Fig. 4 Proportion of grasslands habitat/communities (exotic grassland, native pasture and natural temperate grassland) surveyed with *S. plana* present in the ACT. *Bars* indicate one standard error

Table 2 Survival probability (phi) and recapture probability (p) of *S. plana* during the MRR study at York Park, Canberra, in 2006

Parameter		Variance	S.E.	95 % CI
phi (.)	0.1599	0.0007961	0.028	0.1046–0.2153
p (.)	0.3300	0.0051096	0.072	0.1899–0.4701

Fecundity

Seventy-one *S. plana* females from eight different natural temperate grassland sites were dissected to assess fecundity. A mean of 74 eggs per female was found (27.4 SD) ranging from a minimum of 31 to a maximum of 148. The mean egg length was 2.24 mm (0.17 SD). Eleven percent of females contained more than 100 eggs. Females were observed in the field to lay their eggs on the base of *Rytidosperma* spp. and *Austrostipa* spp. tussocks as well as in tussocks of the exotic *N. neesiana* grass.

Larval habitat use and biology

The larvae of *S. plana* were found in both native grassland (55 larvae) and in *N. neesiana* grassland (37 larvae). Many of larvae (39 %) collected in natural temperate grassland were found in soil among the roots of tall spear grass (*A. bigeniculata*) or a mixture of wallaby grass (*Rytidosperma* spp.) and spear grass (*Austrostipa* spp.; Fig. 6). Nearly 20 % of *S. plana* larvae collected were confined to *Rytidosperma*. The larvae ranged from a minimum of 6 mm to a maximum of 28 mm in length. At all four sites (two native habitats, two Chilean needlegrass dominated habitats) we found very small (6–13 mm), medium (>13–20 mm) and large (>20 mm) sized individuals. All three size classes

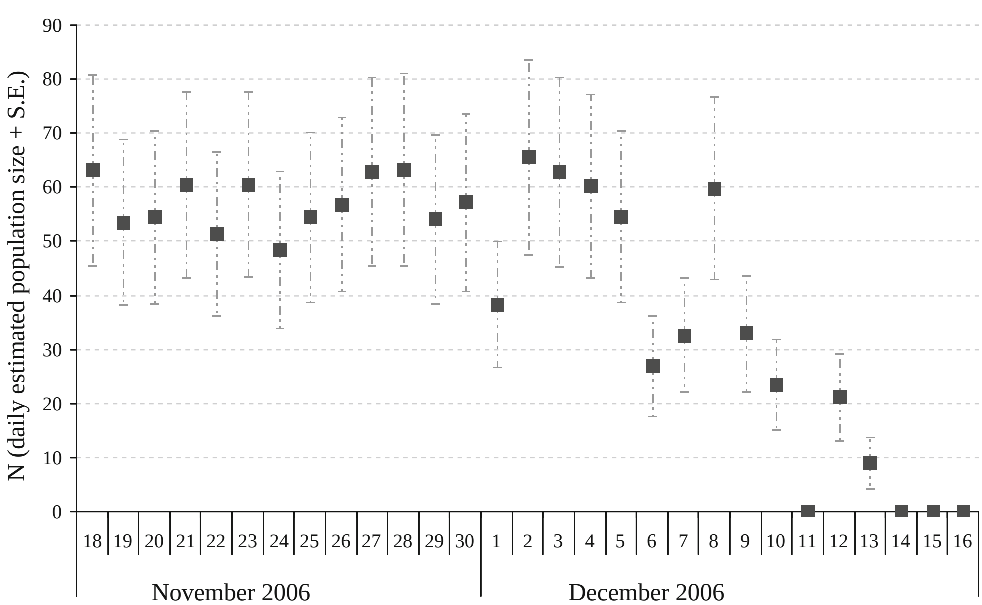

Fig. 5 Temporal variation in abundance during the flight season between 18 Nov and 6 Dec in 2006 for the *S. plana* population at York Park, Canberra, ACT. *Bars* indicate one standard error

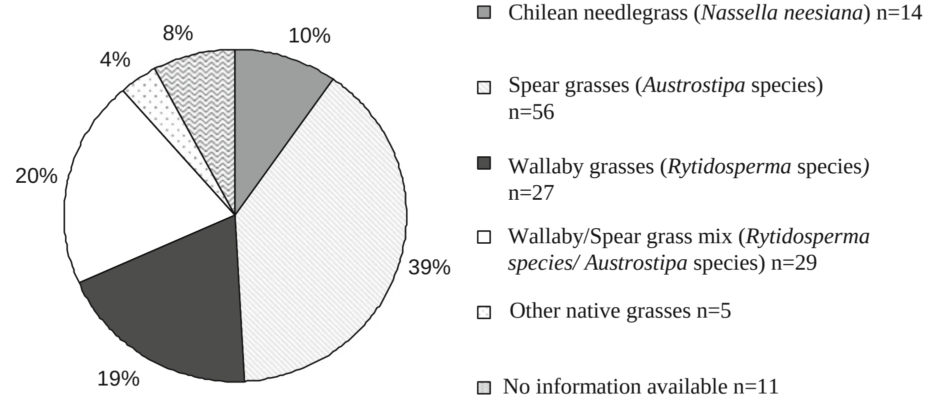

Fig. 6 Occurrence of *S. plana* larvae (percentages) found in tussocks of different species of grasses in the ACT

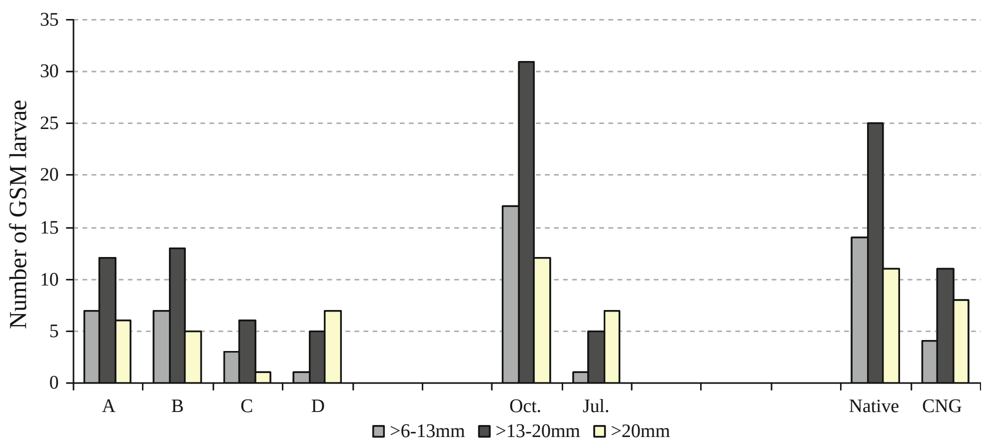

Fig. 7 Abundance of *S. plana* larvae (number of individuals found) shown as numbers found at selected study sites (shown as *A*–*D*), numbers found during July and October and numbers found according to grassland type (native grassland and Chilean needlegrass). Sites *A* and *B* are situated in Belconnen in the ACT; Sites *C* and *D* are in Yarralumla and McGregor in the ACT. Larval size has been grouped into three classes (6–13, 13–20 and >20 mm) as indicated by shading type in the histograms

were detected during each of the two sampling sessions (July, October) and in native and exotic grasslands. Larvae in the medium size class (>13–20 mm) were substantially more numerous than those in the other two classes (Fig. 7). Larvae collected in Chilean needlegrass dominated habitats were significantly larger than larvae collected in natural temperate grasslands ($F = 12.515$, $df = 1.80$, $p = 0.001$). Larvae ($n = 12$) found prior to the adult flight period (October) were on average 32 mm (SD 1.65) below the soil surface. Most larvae collected were at the uppermost end of a silk-lined burrow.

Discussion

A major finding of our investigation was that *S. plana* is not limited to natural temperate grassland. We detected different life stages (eggs, larvae, adults) in native grasslands dominated by *Rytidosperma* spp., *Austrostipa* spp., as well as in one type of exotic grassland, which is dominated by *Nassella neesiana* (Chilean needlegrass). Populations of *S. plana* in grasslands dominated by *N. neesiana* ranged in size from medium to very high throughout all three flight periods (years) surveyed. Our findings of adult *S. plana* populations in *N. neesiana* grassland support the observations of Braby and Dunford (2006; ACT) and Gilmore et al. (2008; Victoria) of the occurrence of the moths in this type of exotic grassland. Our observation of all life stages of the species specifically in close association with *N. neesiana* indicates that the species is using *N. neesiana* as habitat and as a source of food. This view is strengthened by our observation of gravid females also laying eggs directly on *N. neesiana* and the subsequent emergence of pupae from within these same exotic grasslands (Richter et al. 2012). Thus, it appears that the moths are actively choosing habitat within the *N. neesiana* swards. It was particularly surprising that the *S. plana* larvae were significantly larger in body size in *N. neesiana* dominated habitats than those found in native grasslands.

Two possible scenarios are proposed to explain the association between *N. neesiana* and *S. plana*. Firstly, extant, but perhaps declining, populations of *S. plana* have increased in size in situ in response to increasing dominance of the sites by *N. neesiana*; or, secondly, there has been a switch in the dietary preference of the moths from native grass species to *N. neesiana* following invasion by this species. Postulating a dietary shift to favour the exotic grass species is not without precedence—such host plant shifts from native to exotic host species have been observed in other species of herbivorous insects (Connor et al. 1980). *Nassella neesiana* originated in South America and, from an historical biogeographic point of view, this is extremely interesting given the former vicariance by means of the Trans-Antarctic connection (Bremer 2002). Phylogenetic studies have revealed that, through this connection, ancestors of major groups of plant taxa were restricted to either or both continents (Bremer and Janssen 2006). Thus, it can be hypothesised that the South American grass *N. neesiana* and some Australian native grasses, in particular spear grass (*Austrostipa* spp.), that are similar in morphological characteristics to *N. neesiana*, may have a common origin that might facilitate the apparent dietary expansion or shift that we hypothesise in *S. plana*. The significantly larger body size of larvae of *S. plana* present in the *N. neesiana* grasslands might be explained by differences in the nutritional value of this species; however this possibility requires further research.

Another major finding of our investigation is that many populations of *S. plana* were characterised by continuing low abundance in successive years, with only six sites supporting large populations (hundreds of individuals detected in a 20 min survey) over the period of our investigation. The apparent ability of the species to maintain similar densities across time among *S. plana* populations is underpinned by the comparison of results from past mark recapture release studies and our present study conducted at one location (York Park). We found that there was little variation in the number of seasonal captures (total catches of unique individuals for the years that survey data was available) of male *S. plana* over well-separated census periods [1992: 317 individuals, 1993: 321, 1994: 375, 2006: 398; data from Rowell (2012)]. The occurrence of large numbers of *S. plana* (>100 individuals during a single census) within small and large grassland remnants (this study; Clarke and Dunford 1999; Edwards 1993) indicates that, provided sites are managed properly, the species might be largely unaffected by the size of the native grassland patch.

Edwards (1994) suggested that the length of the larval period is probably 2–3 years, and this is supported by our data. Based on larval size, we found the co-occurrence at sites of at least three cohorts of larvae just prior to emergence in October—these larvae represented very small individuals (>6–13 mm) that were clearly from eggs laid 12 months earlier, larger larvae (>13–20 mm) that must have been at least in their second year of life and much larger larvae (>20 mm) approaching pupation that must have been at least 3 years of age. In temperate regions, insect larvae often face a pathway decision between continuing growth and development to the adult stage or delaying the time of emergence until the next season (Gotthard 2008). This decision is dependent on the day length, temperature and quality of the host plant experienced by the larvae (Danilevskii 1965; Friberg and Wiklung 2010). Long days combined with high temperature and high quality host plants typically support continued development. By contrast, short day length, cold temperature and poor quality host plants at the beginning of colder seasons trigger entry into diapause (Friberg et al. 2012). Nothing is known about the drivers of larval development for *S. plana* and the discovery of distinct larval cohorts needs further research to better understand the species larval biology and its relationship to the ecological factors driving the moth's demography.

Association with Chilean needlegrass

Our quantitative findings of an association between adult and larval *S. plana* and the exotic Chilean needlegrass (*N. neesiana*) present a dilemma for managers: how do they balance the needs of the threatened populations of *S. plana* that have occupied large patches of *N. neesiana*, a weed of national significance, with the need to control the exotic grass at these sites? In the ACT, some very large populations have been reduced greatly in size (and are under threat of elimination) from the spraying of *N. neesiana* infestations. Dietary analysis and studies under natural conditions regarding the species habitat affinity to select or even prefer the exotic grass are urgently required to determine the extent to which *N. neesiana* and grasslands are used as host plants and habitat for reproduction. We speculate that the presence of *N. neesiana* may prove inadvertently to be an important low cost component in the conservation of populations of *S. plana* at sites that are seriously disturbed and that have few other conservation values. It is important to note that all *N. neesiana* grasslands in the ACT, where *S. plana* were found, are surrounded by native grasslands. It is likely that this highly invasive grass has only recently moved into these grasslands (after 1970). It is thus not clear whether golden sun moth populations have moved from natural temperate to exotic grassland or, more likely, comprise remnants of existing populations that have responded in situ to the spread of *N. neesiana* into natural temperate grasslands. These aspects of the potential causes of the species current food plant utilisation and habitat preference need to be considered in the ongoing discussion about the species' conservation status (Gilmore and Harvey 2010; New 2012).

Implications for monitoring and conservation

It has been difficult to formulate specific conservation actions for *S. plana* because of a lack of standardised monitoring protocols and a limited knowledge about the ecology of the species (Gibson and New 2007). Our research has come some way towards improving this situation. The mark-release-recapture (MRR) performed on one *S. plana* population provided information about the adult life span under natural conditions; survival probability and total population size at the height of the flight period. Generally among monitoring methods, there are two ways to estimate the size of a population. The first method, counting individuals along predefined transect lines (transect counts), is widely applied in extensive large-scale and/or long-term monitoring programs (Nowicki et al. 2008) like the British Butterfly Monitoring Scheme (Pollard and Yates 1993) and the European Grassland Butterfly Indicator (van Swaay and van Strien 2005). This method estimates the relative abundance of a population. The second method, MRR, has been largely restricted to intensive small-scale and short-term research projects (Nowicki et al. 2008). It is very time consuming requiring the marking and recapture of individuals. The advantage of this approach is that it is reliable and estimates the absolute abundance of the population. Moreover it allows for imperfect detection of individuals and for temporal fragmentation of the population (Nowicki et al. 2008). Mark Release Recapture studies provide a base line value for true abundance that can be compared with the transect methods. Because of this, MRR can be used to assess the impact of threats on the survival of the species and provides a reliable approach to determining the efficiency of management actions (Lettink and Armstrong 2003). For example, information derived from MRR can be implemented in Species Viability Analysis to develop recovery criteria for endangered insect species (Schultz and Hammond 2003). We recommend that MRR be used as a component of the procedures for long term monitoring of *S. plana* populations at important sites that are likely to be subject to management intervention.

According to the EPBC Act (Australian Government 2009), surveys for *S. plana* should be designed to maximise the chance of detecting the species; with consideration being given to the time of the year (season), sampling effort and conditions. The moths are most active during the warmest part of the day (between 10:00 and 14:00 h), with temperatures above 20 °C, minimal cloud cover and little or no wind (Clarke and O'Dwyer 2000; Gibson and New 2007). We showed that the daily activity pattern of flying *S. plana* adults is characterised by a series of peaks during the day with a clear preference for activity between 11 a.m. and 2 p.m. The activity pattern of many species is profoundly influenced by abiotic factors such as solar radiation, temperature, wind and humidity. This is in particular true for ectotherms such as butterflies, which rely on suitable abiotic conditions because of their reduced thermal inertia (sensu Rutowski et al. 1994). For many butterfly species, daily activity is reduced during very high temperatures to avoid desiccation (Van Der Have 2002). On the other hand, specific (high) temperatures are needed to allow successful mating and egg deposition. Very low temperatures may result in low mating success and an increase in predator pressure (Van Der Have 2002). These factors need to be considered when comparing the results of surveys and monitoring that involves *S. plana*. Measures of local weather conditions that strongly influence the activity of the moths include wind speed, solar radiation and air and ground surface temperature.

Local weather conditions and seasonal trends in climate are likely to have a profound role in shaping aspects of larval development, adult activity, population demography and feeding behavior. So far, little attention has been given to understanding the influence of climatic variables on the survival of *S. plana*. It is very likely that in the near future the unique climate pattern in temperate south eastern Australia—characterised by prolonged droughts, fires, hot summers and cold winters—will be subject to pronounced change, with more prolonged severe droughts, warmer winters, increasing numbers of thunder storms and significant rainfall events increasing in occurrence (CSIRO 2007). Moreover, these changes in climate are likely to be accompanied by increased levels of invasion by non-native plants. This factor alone compels us to recommend further research be undertaken that focuses on the critical impact that climate change may have on the survival of this remarkable species and its endangered grassland habitat.

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YORK PARK
GOLDEN SUN MOTH MONITORING
2013

Report prepared for
Section 22 Barton Pty Ltd

by

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1 INTRODUCTION

Robert Jessop Pty Ltd (RJPL) prepared this monitoring report on behalf of Section 22 Barton Pty Ltd to meet the 2014 annual reporting requirements of the *Potential shading impacts on York Park golden sun monitoring plan* (RJPL 2014, the monitoring plan). The monitoring plan was developed to meet Commonwealth *Environment Protection Biodiversity Conservation Act* (*EPBC Act*) approval decision (*EPBC 2012/6606*) conditions for development of a hotel and carpark at Block 14 Section 22 Barton (14/22 Barton). The report contains detailed descriptions of the site, proposed actions and monitoring procedures (RJPL 2014).

This report presents the Year 1 baseline surveys undertaken in spring and summer 2013 for flying golden sun moth (*Synemon plana*, GSM), GSM pupal cases and vegetation condition at York Park.

Assessment and analysis of the monitoring data is not required until after the 3rd year of data collection during the 2015 GSM flying season once post-shading data becomes available. Assessment of the effectiveness of the Natural Temperate Grassland Maintenance Plan (Parsons Brinkerhoff 2008), in the context of potential shading impacts, are also not feasible until several years of data have been collected and analysed.

2 METHODS

2.1 Regional GSM Information

GSM information, including sightings, general locations and activity levels around the ACT region were shared by researchers and consultants via email on a weekly basis during the GSM flying season. Conservation Planning and Research (CPR) subsequently compiled this data to provide a summary of GSM activity recorded throughout the region between October and December 2013.

2.2 Survey Area and Quadrat Placement

The survey area defined in the monitoring plan (RJPL 2013) incorporates the York Park GSM site, and excludes the area proposed for road access to 14/22 Barton and areas of exotic perennial grasses and native *Poa* plantings (Rowell 2012). The site is stratified into the following four zones for the pupal case surveys and vegetation assessments, as specified in the monitoring plan:

- Zone 1a: shaded by the proposed development at 14/22 Barton (impact);
- Zone 1b: shaded by the proposed development at 14/22 Barton and potentially shaded by the proposed development at Part 3/22 Barton;
- Zone 2a: unshaded by the proposed development at 14/22 Barton and unshaded by the proposed development at Part 3/22 Barton (control); and
- Zone 2b: unshaded by the proposed development at 14/22 Barton but potentially shaded by the proposed development at Part 3/22 Barton.

Twenty-four, 1 m^2 quadrats were established across the site at the beginning of the first season, marked using temporary pegs at ground-level and the location recorded with GPS. Appendix A presents GPS point locations and a map of indicative quadrat placements. Pegs facilitated relocation of the quadrats for repeat sampling during the season and were removed at the end of the season.

Quadrats were distributed across the control and impact zones to obtain representative data for each zone. As the data to be analysed would be the average number of pupal cases detected (i.e. total number of pupal cases per zone divided by the number of quadrats per zone; refer Section 2.5.3), variation in the proportional differences in quadrat number to zone size would not skew analysis results or interpretation. Table 1 presents a summary of survey zones and quadrat distribution.

Table 1. Survey zone summary and quadrat distribution.

Zone	Block Shading		Control / Impact	Area (m^2)	Number of Quadrats
	14/22 Barton	***Part 3/22 Barton***			
1a	Shaded	Unshaded	Impact	1,715	9
1b	Shaded	Shaded	(Impact)	375	3
2a	Unshaded	Unshaded	Control	1,800	9
2b	Unshaded	Shaded	(Control)	490	3

2.3 GSM Flying Surveys

Flying GSM surveys were conducted in a manner consistent with the ACT Government (2010) GSM survey guidelines and with the annual monitoring approach presented in Parsons Brinkerhoff (2008) and refined in Umwelt (*in prep*) to better reflect GSM activity across the York Park GSM site, as follows:

- Flying GSMs were counted along two 100 m transects along the long axis of York Park (Figure 1) and recorded as number of GSM per 100 m transect.
- The transect surveys were undertaken three times approximately half an hour apart.
- Two sets of rotational point counts, involving 10 repeated, 30 second rotational counts, were conducted at one site in the centre of the York Park GSM site between the transect surveys (Figure 1). All GSM seen in a radius of 25 m were recorded. Any individuals that re-crossed the observer’s visual path were double counted. Averages were calculated from the ten rotations at each point to provide number of GSM per 30 second rotation.

Despite attempts to ensure that all data was consistent, the flying moth survey undertaken by Umwelt Pty Ltd differs from the monitoring protocol outlined in the monitoring plan (RJPL 2014) in that rotational point counts were conducted at a single central site rather than at two separate sites at the northern and southern ends of the York Park GSM site. Section 5 outlines the implications of this and a proposed response.

The start of the GSM flying season was confirmed using known reference sites in the ACT, including York Park, and consultation with the ACT GSM monitoring group.

Other on-site weather data was recorded during all field surveys of flying GSM. Again these records shall be used to assist with interpreting the GSM survey results on a year to year basis. Umwelt Pty Ltd recorded the following data during flying moth surveys:

- wind speed and direction; and
- air temperature.

Umwelt Pty Ltd did not record cloud cover during flying moth surveys.

2.4 Pupal Case Monitoring

Pupal case surveys were conducted based on the quadrat survey approach outlined by Richter *et al*. (2013). While Richter *et al.* (2013) recommended a sample of 12 sampling quadrats for pupal case surveys, 24 quadrats were chosen to better identify the potential impacts of shading at the York Park GSM site.

Pupal cases were counted in each quadrat every two weeks over a six week period (i.e. 3 times) during the GSM flying period from early-to-mid November until late December. All cases detected were removed for identification (e.g. using microscopy) and possible sexing. This would ensure that individual pupal cases were counted in one survey only.

2.5 Vegetation Monitoring

Data recorded for each quadrat included:

- all species present;
- the dominant species (single or multiple); and
- cover / abundance (%) using the Braun-Blanquet cover / abundance classes outlined in ACT Government (2010b).

Floristic value scores were calculated from abundance data based on Rehwinkel (2007) consistent with ACT Government (2010b).

2.6 Soil Temperature Monitoring

On-site soil temperature monitoring within shaded and un-shaded areas commenced on 9 May 2014. The first collection of data from temperature loggers is anticipated to be undertaken during vegetation surveys in spring 2014. On-site soil temperature data is therefore not included in this report.

2.7 Meteorological Data

No analyses or interpretation requiring the use of meteorological data from the Bureau of Meteorology are proposed prior to the 2015 flying season. Meteorological data from Canberra Airport for 2013 and 2014 would be obtained from the Bureau of Meteorology following the GSM flying season in 2015 to contribute to the first analyses of potential shading impacts. This will not have any effect on the content of the data. Data would subsequently be obtained annually to contribute to annual analyses.

3 RESULTS

3.1 Regional GSM Information

Data compiled by CPR indicated that GSM were confirmed flying at York Park by three different consultants and researchers on 25, 30 and 31 October prior to surveys commencing. GSM activity was reported from other sites in the ACT region in the first week of November. The flying season was confirmed to have started throughout the region by early November, had peak activity occurring around late November, and had GSM activity continuing until mid-to-late December (CPR, unpublished data).

3.2 GSM Flying Surveys

Due to Section 22 Barton Pty Ltd's negotiations with the Commonwealth Departments of Finance (DoF) and Environment (DoE) during the 2013 flying season and preparation of the GSM monitoring plan (RJPL 2014), Umwelt Pty Ltd (Umwelt, *in prep*) conducted flying moth surveys in 2013 on behalf of the DoF. Umwelt Pty Ltd provided all data to Section 22 Barton Pty Ltd with the DoF's permission.

Umwelt Pty Ltd surveyed GSM flying moths on three occasions approximately two weeks apart during the GSM flying period. Table 2 presents the dates and weather conditions of each survey. All surveys were conducted on suitable days. Other consultants and researchers also conducted surveys at various sites in the Canberra region and detected flying GSM (CPR, unpublished data).

Table 2. Site conditions during flying moth surveys.

Date	Max Temperature (ºC)	Rainfall (mm)	Wind speed and direction	Cloud cover
19/11/2013	28.0	0	Low, SSW	Not recorded
27/11/2013	29.0	0	Low, WNW	Not recorded
12/12/2013	26.4	0	Low, WNW	Not recorded

Appendix B presents Umwelt Pty Ltd's complete dataset (Umwelt, *in prep*) for the flying moth surveys. Table 3 and Table 4 present aggregated survey results for transect surveys and rotational point counts respectively.

Table 3. Summary of flying GSM numbers - Transect surveys.

Transect	Transect location	Average (1dp)
Transect 1	East	3.9
Transect 2	West	4.9
Combined		4.4

Table 4. Summary of flying GSM numbers - Point count surveys.

Time	Location	Average (1dp)	Range
11:45	Centre	0.4	0 - 3
12:15	Centre	1.4	0 - 6
Combined	Centre	0.9	0 - 6

3.3 Pupal Case Surveys

Pupal case surveys were conducted according to the method specified in the monitoring plan (RJPL 2014) on three occasions two weeks apart. Surveys were undertaken on 24 November 2013, 9 December 2013 and 23 December 2013.

Appendix C presents the complete pupal case survey dataset. Table 5 presents a summary of the pupal case survey results for the control and impact zones. Very low pupal case numbers were recorded, i.e. only one pupal case was recorded in each of Zones 1a and 2a. No pupal cases were recorded in Zones 1b or 2b.

Table 5. Summary of the pupal case surveys within control and impact sites.

Zone	Pupal cases	
	Average (1dp)	Maximum number
Zone 1a	0.1	1
Zone 1b	0	0
Zone 1 (impact)	**0.1**	**1**
Zone 2a	0.1	1
Zone 2b	0	0
Zone 2 (control)	**0.1**	**1**

3.4 Vegetation Surveys

Dominant species, percentage cover and complete species lists, including Braun-Blanquet abundance scores, were collected for each quadrat. All data is presented in Appendix D. Species recorded are shown relative to the York Park GSM site cumulative species list of Rowell (2012), with a summary of the floristic value calculations for each quadrat. Table 6 presents a summary of the key vegetation quality indicators for the control and impact zones.

Table 6. Vegetation survey summary for the control and impact sites.

Zone	Floristic score		Native species	Exotic species	Cover (%)
	Average	Maximum	Average Number (1dp)		Average
Zone 1a	1.7	5	5.6	5.9	79
Zone 1b	1.3	2	6.0	3.7	78
Zone 1 (impact)	**1.6**	**5**	**5.7**	**5.3**	**79**
Zone 2a	1.9	11	4.9	4.5	69
Zone 2b	2.0	6	4.7	4.0	80
Zone 2 (control)	**2**	**11**	**4.8**	**4.3**	**72**

4 ECOLOGICAL INTERPRETATION

All flying moth surveys were undertaken during the peak period of GSM activity in the Canberra area and are consequently valid representations of GSM activity levels at the York Park GSM site. Flying moth numbers observed were consistently low-to-moderate during the surveys based on the semi-quantitative GSM site assessment method developed by David Hogg Pty Ltd (2010). Low-to-moderate GSM numbers are consistent with GSM populations present throughout large areas of GSM habitat within the ACT. Shared data available for regional GSM observations during the 2013 does not provide sufficient information regarding survey effort to compare GSM activity levels between sites.

Rotational point counts undertaken by Umwelt Pty Ltd in 2013 were performed at a single central point, consistent with methods outlined in the Natural Temperate Grassland Maintenance Plan (Parsons Brinkerhoff 2008), but not with the proposed method outlined in the monitoring plan (RJPL 2014). Consequently, the point count data presented in Table 4 would not be not directly comparable to data collected in future years according to the monitoring plan. The information may useful as a qualitative assessment of GSM flying activity.

Two GSM pupal cases were recorded during the pupal case surveys, with one case identified in each of the control and impact zones. This represents a very low rate of detection despite applying approximately 6 times the survey effort recommended by Richter (2013). These very low pupal case numbers are indicative of the challenges when conducting pupal surveys, i.e. that distribution of pupal cases is highly variable and unpredictable.

Quadrats varied in floristic value, diversity, vegetation cover and weed presence, but overall were indicative of partially degraded natural temperate grassland. Vegetation in 3 quadrats within each of the control and impact zones had a floristic score of 4 or greater, nominally meeting the criteria of Rehwinkel *et al.* (2007) for inclusion in the natural temperate grassland endangered ecological community. Floristic scores within the control zone were generally marginally greater, as indicated by the slightly higher average floristic sore. Sites in the impact zone had marginally higher native and exotic species diversity, and slightly higher vegetation cover. Vegetation data is likely to be highly comparable across seasons and provides valuable data for future BACI analyses.

Overall, the year 1 baseline surveys demonstrates that GSM are present in low to moderate numbers at the York Park GSM site, with pupal cases detected at very low numbers (i.e. 2), within both the control and impact areas. Vegetation surveys confirmed that the York Park GSM site supports partially degraded natural temperate grassland, the majority of which is potential GSM breeding habitat.

5 COMPLIANCE WITH THE GSM MONITORING PLAN

5.1 Survey Requirements

Transect surveys, pupal case surveys and vegetation surveys were conducted according to the methods specified in the monitoring plan (RJPL 2014). Rotational point counts were undertaken at a single central location rather than at two locations at the northern and southern ends of the York Park GSM site, as specified in the monitoring plan.

The inconsistency of rotational point count surveys has arisen due to the need to use flying moth survey data collected by Umwelt Pty Ltd in accordance with DoF and DoE requirements. While RJPL understood that data to be collected by Umwelt Pty Ltd would be consistent with methods outlined in the monitoring plan, rotational point count data was recorded at a single central location following the annual monitoring approach presented in Parsons Brinkerhoff (2008). It is unlikely that observations at the central point would differ greatly from observations at either end due to the small site and the relative mobility of flying male moths. Data would nonetheless not be directly comparable.

RJPL recommends that future rotational point count surveys be undertaken at both the central location, as described in Parsons Brinkerhoff (2008), and at the northern and southern ends of the site as described in the GSMMP (RJPL 2014). This would permit:

- comparison of baseline data for the central point collected over 2 flying seasons (i.e. 2013 and 2014) with post impact data to determine general trends in GSM activity at the York Park GSM site.
- comparison of data from northern and southern points in an attempt to identify potential differential changes in flying moth activity in the northern and southern parts of the site. Results would be interpreted with respect to general trends at the site using data from the central point. The lack of independence of the northern and southern site due to their close proximity and the ability of flying male GSM to freely move between ends of the site would also be considered.

5.2 Reporting Requirements

The GSM monitoring plan (RJPL 2014) requires that annual monitoring reports meet the following specifications:

> Annual monitoring and compliance reports would be prepared in a timely manner (e.g. February for the annual monitoring report) each year meeting the *EPBC Act* approval requirements (Conditions 3, 8) by:
>
> - providing and assessing the monitoring data for the previous twelve months against the baseline conditions;
> - concluding whether or not there has been a decline in the population of GSM within the area of York Park shaded as a result of the action, taking into account regional population trends and local ecological conditions; and
> - reviewing the GSMMP's applicability in achieving its objectives (Condition 8) to determine whether, under *EPBC Act* approval Condition 10, the GSMMP should be revised in consultation with the Commonwealth.
>
> When preparing the report, reference would be made to the current NTGMP and any relevant management and monitoring changes relevant to a review of this GSMMP.

The current report represents the first monitoring report of baseline data. The above requirements for analysis against the baseline conditions and assessment of whether there has been a decline in the population of GSM at York Park do not yet apply.

The preparation of this report was originally scheduled for February 2014, but necessarily delayed due to the organisation of approvals and the establishment of the monitoring program. The preparation of this report consequently fulfils the reporting requirements for year 1 as specified in the monitoring plan (RJPL 2014).

6 CONCLUSION

This report provides baseline results of flying moth surveys, pupal case surveys and vegetation surveys for 2013 in accordance with the *Potential shading impacts on York Park golden sun monitoring plan* (RJPL 2014, the monitoring plan). Data is provided in summarised form suitable for incorporation into future analyses of potential impacts. Appendices A to D present all survey data. Detailed data analysis was not undertaken, as 2013 is the first year of data collection and no winter shading of the York Park GSM sight has occurred.

The surveys confirmed the presence of GSM at low to moderate activity levels within the York Park GSM site, confirmed the low detection rates of pupal cases, and confirmed the vegetation classification within the York Park GSM site as natural temperate grassland. Vegetation condition was generally consistent between the control and impact zones although some minor variation was present between quadrats.

Surveys were conducted in a manner consistent with the survey requirements outlined in the monitoring plan (RJPL 2014), with the exception of the rotational point counts which were conducted at the centre of the site rather than at the northern and southern ends of the site. This report also fulfils requirements for reporting the year 1 baseline monitoring data outlined in the monitoring plan (RJPL 2014).

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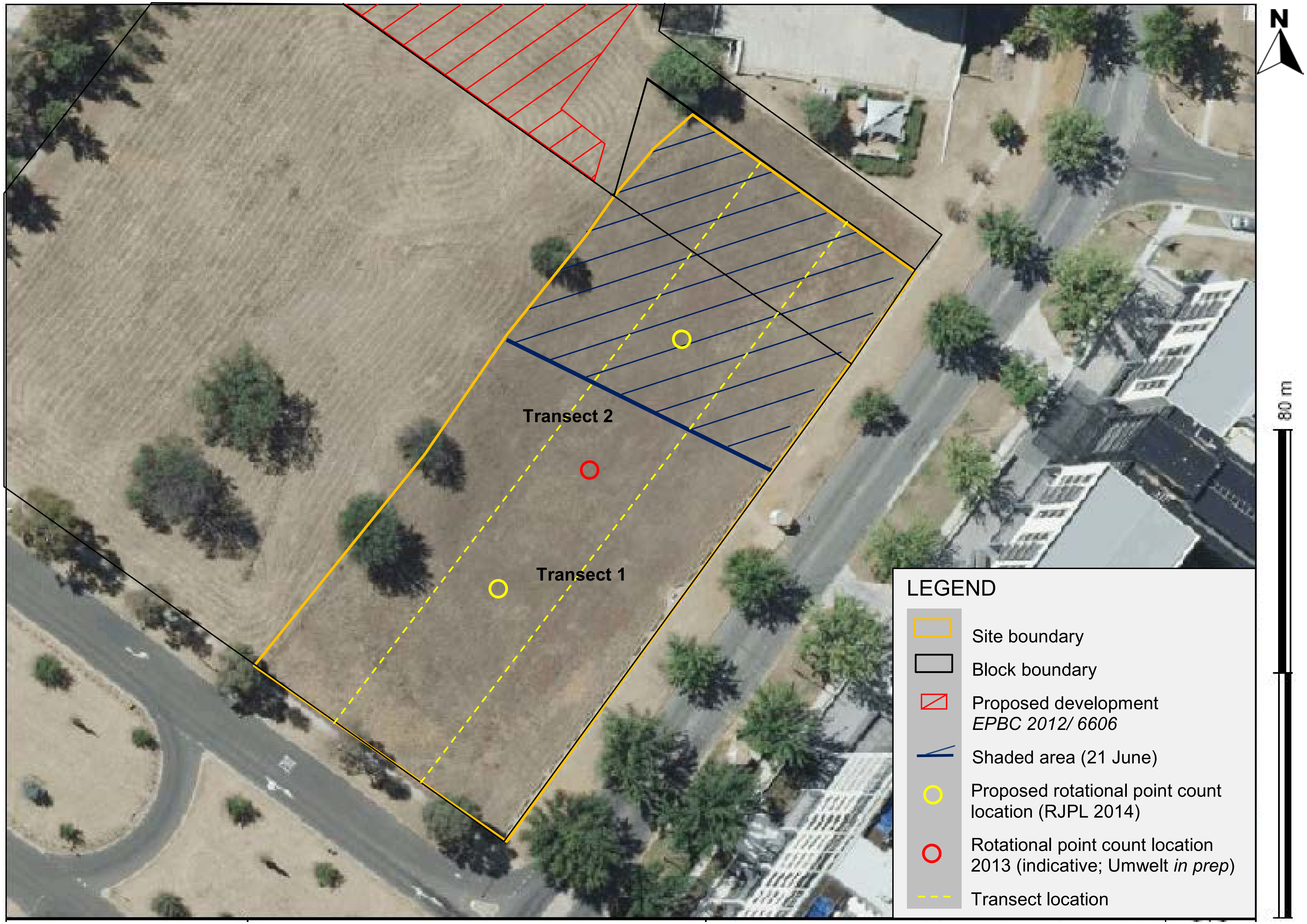

Figure 1. York Park GSM site flying moth survey details 2013.

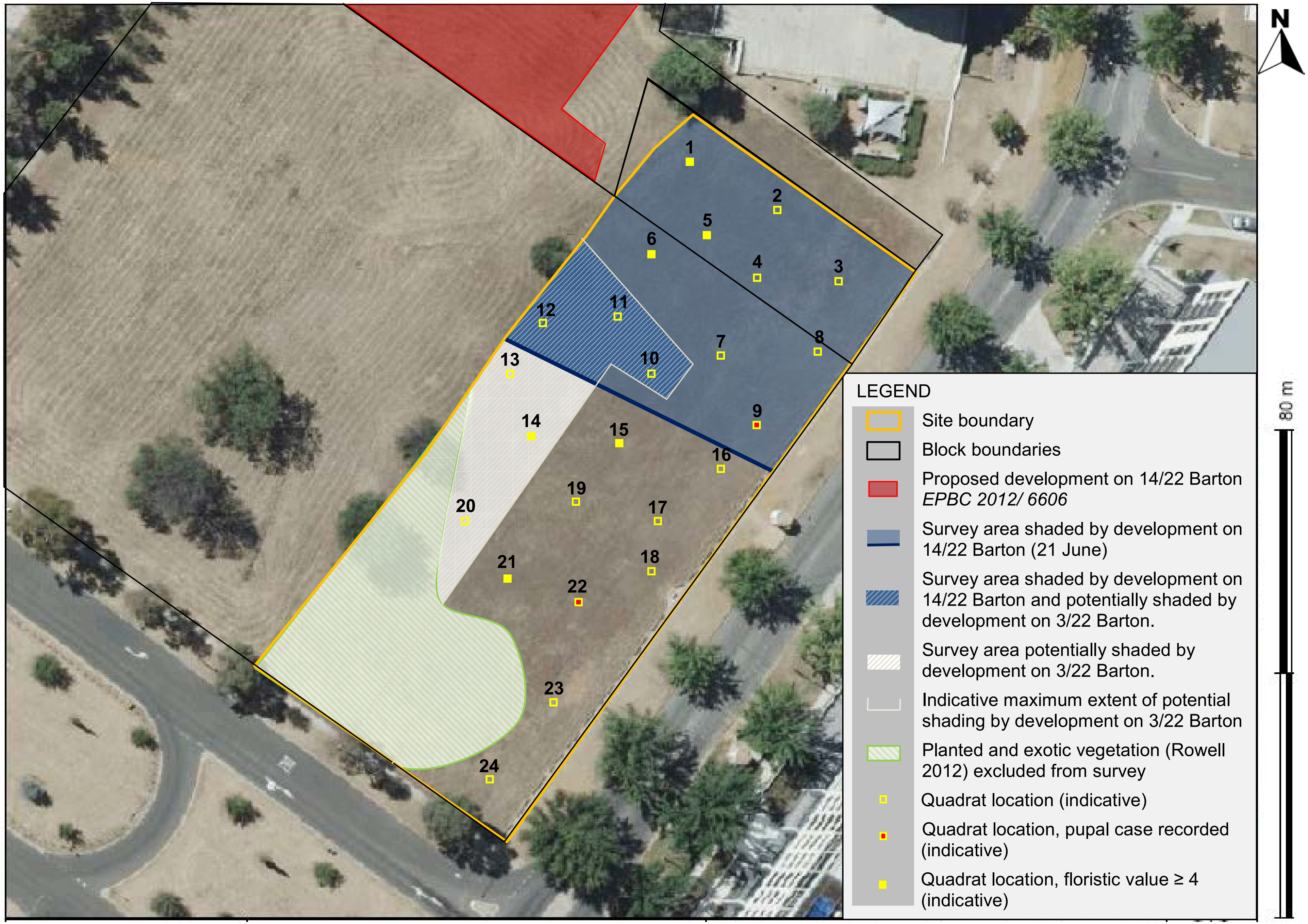

Figure 2. York Park GSM site pupal case and vegetation survey summary.

APPENDICES

APPENDIX A – QUADRAT DETAILS

Quadrat	Control or impact site	Zone	X	Y
1	Impact	1a	693852	6090343
2	Impact	1a	693867	6090336
3	Impact	1a	693876	6090322
4	Impact	1a	693866	6090328
5	Impact	1a	693855	6090330
6	Impact	1a	693847	6090327
7	Impact	1a	693849	6090314
8	Impact	1a	693872	6090309
9	Impact	1a	693856	6090304
10	Impact	1b	693842	6090312
11	Impact	1b	693839	6090320
12	Impact	1b	693828	6090321
13	Control	2b	693825	6090311
14	Control	2b	693824	6090302
15	Control	2a	693836	6090301
16	Control	2a	693851	6090295
17	Control	2a	693841	6090284
18	Control	2a	693843	6090278
19	Control	2a	693828	6090294
20	Control	2b	693816	6090284
21	Control	2a	693823	6090279
22	Control	2a	693833	6090274
23	Control	2a	693828	6090255
24	Control	2a	693815	6090244

APPENDIX B – FLYING MOTH SURVEY 2013

Appendix B - Table 1: Flying moth surveys 2013 – transects.

Date	Transect	Moth numbers			Moth numbers
		1130	1200	1230	Average (1dp)
19/11/2013	Transect 1	4	4	5	4.7
27/11/2013	Transect 1	3	10	5	6.0
12/12/2013	Transect 1	1	0	2	1.0
19/11/2013	Transect 2	1	4	1	2.0
27/11/2013	Transect 2	2	12	9	7.7
12/12/2013	Transect 2	1	5	9	5.0

Appendix B - Table 2: Flying moth surveys 2013 – point observations.

Date	Time	Point	Moth numbers	
			Average (1dp)	Range
19/11/2013	11:45	Centre	0.7	0 - 3
27/11/2013	11:45	Centre	0.3	0 - 1
12/12/2013	11:45	Centre	0.2	0 - 1
19/11/2013	12:15	Centre	0.5	0 - 2
27/11/2013	12:15	Centre	0.0	0
12/12/2013	12:15	Centre	3.6	0 - 6

APPENDIX C – PUPAL CASE SURVEY 2013

Date	Survey	Quadrat	Control or Impact site	Zone	Pupal case numbers	Notes
24/11/2013	1	1	Impact	1a	0	
24/11/2013	1	2	Impact	1a	0	
24/11/2013	1	3	Impact	1a	0	
24/11/2013	1	4	Impact	1a	0	
24/11/2013	1	5	Impact	1a	0	
24/11/2013	1	6	Impact	1a	0	
24/11/2013	1	7	Impact	1a	0	
24/11/2013	1	8	Impact	1a	0	
24/11/2013	1	9	Impact	1a	1	
24/11/2013	1	10	Impact	1b	0	
24/11/2013	1	11	Impact	1b	0	
24/11/2013	1	12	Impact	1b	0	Robber fly pupal case
24/11/2013	1	13	Control	2b	0	
24/11/2013	1	14	Control	2b	0	
24/11/2013	1	15	Control	2a	0	
24/11/2013	1	16	Control	2a	0	
24/11/2013	1	17	Control	2a	0	
24/11/2013	1	18	Control	2a	0	
24/11/2013	1	19	Control	2a	0	
24/11/2013	1	20	Control	2b	0	
24/11/2013	1	21	Control	2a	0	
24/11/2013	1	22	Control	2a	1	
24/11/2013	1	23	Control	2a	0	
24/11/2013	1	24	Control	2a	0	
9/12/2013	2	1	Impact	1a	0	
9/12/2013	2	2	Impact	1a	0	
9/12/2013	2	3	Impact	1a	0	
9/12/2013	2	4	Impact	1a	0	
9/12/2013	2	5	Impact	1a	0	
9/12/2013	2	6	Impact	1a	0	
9/12/2013	2	7	Impact	1a	0	
9/12/2013	2	8	Impact	1a	0	
9/12/2013	2	9	Impact	1a	0	
9/12/2013	2	10	Impact	1b	0	
9/12/2013	2	11	Impact	1b	0	
9/12/2013	2	12	Impact	1b	0	
9/12/2013	2	13	Control	2b	0	
9/12/2013	2	14	Control	2b	0	
9/12/2013	2	15	Control	2a	0	
9/12/2013	2	16	Control	2a	0	
9/12/2013	2	17	Control	2a	0	

Date	Survey	Quadrat	Control or Impact site	Zone	Pupal case numbers	Notes
9/12/2013	2	18	Control	2a	0	
9/12/2013	2	19	Control	2a	0	
9/12/2013	2	20	Control	2b	0	
9/12/2013	2	21	Control	2a	0	
9/12/2013	2	22	Control	2a	0	
9/12/2013	2	23	Control	2a	0	
9/12/2013	2	24	Control	2a	0	
23/12/2013	3	1	Impact	1a	0	
23/12/2013	3	2	Impact	1a	0	
23/12/2013	3	3	Impact	1a	0	
23/12/2013	3	4	Impact	1a	0	
23/12/2013	3	5	Impact	1a	0	
23/12/2013	3	6	Impact	1a	0	
23/12/2013	3	7	Impact	1a	0	
23/12/2013	3	8	Impact	1a	0	
23/12/2013	3	9	Impact	1a	0	
23/12/2013	3	10	Impact	1b	0	
23/12/2013	3	11	Impact	1b	0	
23/12/2013	3	12	Impact	1b	0	
23/12/2013	3	13	Control	2b	0	
23/12/2013	3	14	Control	2b	0	
23/12/2013	3	15	Control	2a	0	
23/12/2013	3	16	Control	2a	0	
23/12/2013	3	17	Control	2a	0	
23/12/2013	3	18	Control	2a	0	
23/12/2013	3	19	Control	2a	0	
23/12/2013	3	20	Control	2b	0	
23/12/2013	3	21	Control	2a	0	
23/12/2013	3	22	Control	2a	0	
23/12/2013	3	23	Control	2a	0	
23/12/2013	3	24	Control	2a	0	

APPENDIX D – VEGETATION SURVEY 2013

Appendix D - Table 1: Vegetation structure 2013.

Date	Quadrat	Control or Impact site	Zone	Species		Cover (%)
				Dominant	Co-Dominant	
9/12/2013	1	Impact	1a	*Austrostipa bigeniculata*	*Cynodon dactylon*	80
9/12/2013	2	Impact	1a	*Austrostipa bigeniculata*		95
9/12/2013	3	Impact	1a	*Austrostipa bigeniculata*		75
9/12/2013	4	Impact	1a	*Paspalum dilatatum*		85
9/12/2013	5	Impact	1a	*Austrostipa bigeniculata*		90
9/12/2013	6	Impact	1a	*Austrostipa bigeniculata*		75
9/12/2013	7	Impact	1a	*Bothriochloa macra*		70
9/12/2013	8	Impact	1a	*Bothriochloa macra*	*Rytidosperma sp.*	85
9/12/2013	9	Impact	1a	*Bothriochloa macra*		60
9/12/2013	10	Impact	1b	*Bothriochloa macra*		85
9/12/2013	11	Impact	1b	*Austrostipa bigeniculata*	*Bothriochloa macra*	90
9/12/2013	12	Impact	1b	*Plantago lancifolia*		60
9/12/2013	13	Control	2b	*Austrostipa bigeniculata*		80
9/12/2013	14	Control	2b	*Austrostipa bigeniculata*		70
9/12/2013	15	Control	2a	*Austrostipa bigeniculata*		80
9/12/2013	16	Control	2a	*Bothriochloa macra*		80
9/12/2013	17	Control	2a	*Bothriochloa macra*		90
9/12/2013	18	Control	2a	*Bothriochloa macra*		90
9/12/2013	19	Control	2a	*Austrostipa bigeniculata*		80
9/12/2013	20	Control	2b	*Austrostipa bigeniculata*		90
9/12/2013	21	Control	2a	*Austrostipa bigeniculata*		80
9/12/2013	22	Control	2a	*Paspalum dilatatum*		60
9/12/2013	23	Control	2a	*Avena sativa*	Bare	15
9/12/2013	24	Control	2a	*Austrostipa bigeniculata*	Bare	50

Appendix D - Table 2: Complete species list for the York Park GSM site (Rowell 2012); abundance scores for each species within quadrats.

Scientific name	Common name	Quadrat number																							
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Native grasses																									
Aristida ramosa	Wiregrass						+											r							
Austrodanthonia auriculata	Lobed Wallaby Grass																								
Austrodanthonia bipartita	A Wallaby Grass																								
Austrodanthonia caespitosa	Ringed Wallaby Grass																								
Austrodanthonia carphoides	Short Wallaby Grass	r																							
Austrodanthonia fulva	A Wallaby Grass																								
Austrodanthonia laevis	Smooth Wallaby Grass																								
Austrodanthonia spp.	Wallaby Grasses					+	1	+	2	1		+	1	r	+	1	2	1	+	1	+				
Austrostipa bigeniculata	Tall Speargrass	2	3	2	1	1	1				3	2	1	3	2	3		+		3	2	3	r	r	2
Austrostipa densiflora	A Speargrass																								
Austrostipa scabra	Rough Speargrass			+		+	r	+																	
Bothriochloa macra	Redleg Grass	r	2	2	1	1		3	2	2	2	2	+	+	2	2	3	2	4	1	2	2	2	+	1
Chloris truncata	Windmill Grass																								
Elymus scaber	Wheatgrass	r	1				+											r							
Eragrostis brownii	A Lovegrass																								
Eragrostis trachycarpa	A Lovegrass																								
Microlaena stipoides	Weeping Grass																								
Panicum effusum	Hairy Panic Grass					+	+	1					r	+		r		2		1	1				
Poa labillardieri	Tussock Grass																								
Themeda triandra	Kangaroo Grass																								
Native forbs																									
Acaena ovina	Sheeps Burr																								
Asperula conferta[2]	Common Woodruff																								
Bulbine bulbosa[2]	Golden Lily											r													
Calocephalus citreus[2]	Lemon Beauty Heads														1										
Chamaesyce drummondii	Caustic Weed																								
Cheilanthes sp. [2]																									
Cheilanthes sieberi[2]	Rock Fern															+									
Cheilanthes tenuifolia[2]						r									+										

Scientific name	Common name	Quadrat number																							
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Chenopodium pumilio	Small Crumbweed																								
Chrysocephalum apiculatum[1]	Yellow Buttons	+	2			1	+	2			r	1	1			+									2
Convolvulus angustissimus	Australian Bindweed								r											r					
Crassula sieberiana	Australian Stonecrop																								
Cymbonotus lawsonianus	Bear's Ears																								
Drosera peltata	Sundew																								
Eryngium rostratum[2]	Blue Devil																					r			
Euchiton sp.	A Cudweed																								
Euchiton gymnocephalus	A Cudweed																								
Euchiton sphaericus	A Cudweed																								
Glycine tabacina[2]	Vanilla Glycine																								
Gonocarpus tetragynus[1]	Raspwort																								
Goodenia pinnatifida[2]	Scrambled Eggs	+														1						+			
Hypericum gramineum[2]	Small St John’s Wort																								
Juncus sp.	A Rush																								
Lomandra bracteata[1]	A Matrush																								
Lomandra filiformis[1]	A Matrush					1	+									+				+	r	+			
Lomandra multiflora[2]	A Matrush																								
Lomandra sp. [1]	A Matrush																								
Microtis unifolia[2]	Common Onion Orchid															r				r					
Oxalis perennans	Soursob										r					+									
Pimelea curviflora[2]	Curved Rice-flower																								
Plantago varia[2]	Variable Plantain																								
Rumex brownii	Swamp Dock																								
Schoenus apogon	Bog-rush		r	r			+					1													
Sebaea ovata[2]																									
Senecio quadridentatus	Cotton Fireweed																								
Solenogyne dominii	Smooth Solenogyne																								
Stackhousia monogyna[2]	Creamy Candles																								
Tricoryne elatior[2]	Yellow Rush Lily					r	1						r												
Triptilodiscus pygmaeus[2]	Austral Sunray																								

Scientific name	Common name	Quadrat number																							
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Vittadinia muelleri	Fuzzweed																								
Wahlenbergia sp.	A Bluebell											1	r			+	+			r					
Wahlenbergia communis	Tufted Bluebell																								
Wahlenbergia luteola	A Bluebell		r						+																+
Wahlenbergia stricta	Tall Bluebell							+		1															
Wurmbea dioica[2]	Early Nancy																								
Xerochrysum viscosum[2]	Sticky Everlasting																								
Exotic grasses																									
Aira sp.	A Hairgrass						1	+				+	+	r	+		+	+							
Aira elegantissima	A Hairgrass																								
Avena sp.	Wild Oats	+	r		+			+	r				+	+							+		+	+	+
Avena barbata	Bearded Oats																								
Briza maxima	Blowfly Grass																								
Briza minor	Shivery Grass		+	1	1	1	+		+	+		r			+	r	r	+							
Bromus sp.	A Brome Grass																								
Bromus catharticus	A Brome Grass																								
Bromus diandrus	A Brome Grass																								
Bromus hordeaceus	A Brome Grass																								
Bromus mollis	Soft Brome																								
Cynodon dactylon	Couch																								
Dactylis glomerata	Cocksfoot	2	r		r									r				+			1				
Eleusine tristachya	Goose Grass																								
Eragrostis curvula	African Lovegrass																								
Festuca sp.	A Fine-leaved Fescue																								
Festuca arundinacea	Tall Fescue																								
Lolium perenne	Perennial Ryegrass																								
Lolium rigidum	Ryegrass																								
Lophochloa cristata	Annual Cat's Tail																						1		
Nassella neesiana	Chilean Needlegrass																								
Nassella trichotoma	Serrated Tussock																								
Paspalum dilatatum	Paspalum				2																	1	2		+
Phalaris aquatica	Phalaris																								
Vulpia sp.	Rat's-tail Fescue																								

Scientific name	Common name	Quadrat number																							
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Exotic forbs																									
Acetosella vulgaris	Sorrel																								
Anagallis arvensis	Scarlet Pimpernel																								
Arctotheca calendula	Capeweed																								
Centaurium erythraea	Pink Stars		r	r	r	r		r	+	+		+				+	+	+	+	+			+		
Cerastium glomeratum	Chickweed																								
Cirsium vulgare	Spear Thistle																								
Conyza bonariensis	Flax-leaf Fleabane																								
Echium plantagineum	Paterson’s Curse																								
Erodium cicutarium	Common Crowfoot																								
Galium divaricatum	A Bedstraw																								
Gamochaeta purpurea	A Cudweed																								
Gnaphalium sp.	A Cudweed																								
Hirschfeldia incana	Hoary Mustard																								
Hypericum perforatum	St John’s Wort	1		+			+	r		r		1	1	1	r	r							+		
Hypochaeris glabra	Smooth Catsear																								
Hypochaeris radicata	Catsear		1		+	1	+	1	1	+	1	+				1	+	1		1			+	1	+
Lactuca serriola	Prickly Lettuce																								
Lepidium africanum	A Peppercress																								
Parentucellia latifolia	Common Bartsia																								
Petrorhagia nanteulii	Proliferous Pink			r	r																				
Plantago lanceolata	Ribwort Plantain	1		1	2	+	+	+	1	2		+	1	1	+		+	2	3	r	2	1	+		
Romulea rosea	Onion Grass																								
Salvia verbenaca	Wild Sage																								
Silene gallica	French Catchfly																								
Sonchus oleraceus	Common Sow-thistle																								
Tragopogon porrifolius	Salsify																								
Trifolium angustifolium	Narrow leaf Clover																								
Trifolium arvense	Haresfoot Clover			1				1	1	r								1	1						
Trifolium campestre	Hop Clover																								
Trifolium dubium																									
Trifolium glomeratum	Clustered Clover																								
Trifolium striatum																									

Scientific name	Common name	Quadrat number																							
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Trifolium spp.	Clovers			+					+								r	r	r						
Exotic shrubs and trees																									
Cotoneaster sp.	Cotoneaster																								
Crataegus monogyna	Hawthorn																								
Ligustrum sinense	Small-leaved Privet																								
Populus nigra var. *italica*	Lombardy Poplar																								
Prunus sp.	Plum																								
Sorbus domestica	Service Tree																								

[1]*Indicator species level 1,* [2]*Indicator species level 2*

Appendix D - Table 3: Summary of floristic score metrics 2013.

Indicator	Quadrat number																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Number of common species:	4	5	4	2	5	7	5	4	3	3	5	5	4	3	6	3	6	2	7	4	2	2	2	3
Number of indicator level 1 species:	1	1	0	0	2	2	1	0	0	1	1	1	0	0	2	0	0	0	1	1	1	0	0	1
Number of indicator level 2 species:	1	0	0	0	2	1	0	0	0	0	1	1	0	2	3	0	0	0	0	0	2	0	0	0
Total number of native species:	6	6	4	2	9	10	6	4	3	4	7	7	4	5	11	3	6	2	8	5	5	2	2	4
Number of exotic species:	4	5	7	8	4	5	7	7	6	1	6	4	5	4	4	6	8	4	3	3	2	7	2	3
Number of significant weed species:	1	0	1	0	0	1	1	0	1	0	1	1	1	1	1	0	0	0	0	0	0	1	0	0
Site value score:	4	1	0	0	4	5	1	0	0	0	2	2	0	6	11	0	0	0	1	0	5	0	0	1

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Prepared for Section 22 Barton Pty Ltd
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YORK PARK

GOLDEN SUN MOTH MONITORING 2014

Report prepared for
Section 22 Barton Pty Ltd

by

ROBERT JESSOP PTY LTD

February 2015

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CONTENTS

Figures

Tables

1 INTRODUCTION

Robert Jessop Pty Ltd (RJPL) prepared this monitoring report on behalf of Section 22 Barton Pty Ltd to meet the 2015 annual reporting requirements of the *Potential shading impacts on York Park golden sun monitoring plan* (RJPL 2014a, the monitoring plan). The monitoring plan was developed to meet Commonwealth *Environment Protection Biodiversity Conservation Act* (*EPBC Act*) approval decision (*EPBC 2012/6606*) conditions for development of a hotel and carpark at Block 14 Section 22 Barton (14/22 Barton). The report contains detailed descriptions of the site, proposed actions and monitoring procedures (RJPL 2014a).

This report presents the Year 2 baseline surveys undertaken in spring and summer 2014 for flying golden sun moth (*Synemon plana*, GSM), GSM pupal cases and vegetation condition at York Park.

Year 1 baseline surveys are presented in the York Park Golden Sun Moth Monitoring 2013 survey report (RJPL 2014b) and, where relevant, have been referenced for comparison. Assessment and analysis of the monitoring data is not required until after the 3rd year of data collection during the 2015 GSM flying season once post-shading data becomes available. Assessment of the effectiveness of the Natural Temperate Grassland Maintenance Plan (Parsons Brinkerhoff 2008), in the context of potential shading impacts, are also not feasible until several years of data have been collected and analysed.

2 METHODS

2.1 Regional GSM Information

GSM information, including sightings, general locations and activity levels around the ACT region were shared by researchers and consultants via email on a weekly basis during the GSM flying season. Consultant Alison Rowell subsequently compiled this data to provide a summary of GSM activity recorded throughout the region between October 2014 and January 2015 (A. Rowell pers. comm.).

2.2 Survey Area and Quadrat Placement

The survey area defined in the monitoring plan (RJPL 2014a) incorporates the York Park GSM site, and excludes the area proposed for road access to 14/22 Barton and areas of exotic perennial grasses and native *Poa* plantings (Rowell 2012). As specified in the monitoring plan the site is stratified into the following four zones for the pupal case surveys and vegetation assessments:

- Zone 1a: shaded by the proposed development at 14/22 Barton (impact);
- Zone 1b: shaded by the proposed development at 14/22 Barton and potentially shaded by the proposed development at Part 3/22 Barton;
- Zone 2a: unshaded by the proposed development at 14/22 Barton and unshaded by the proposed development at Part 3/22 Barton (control); and
- Zone 2b: unshaded by the proposed development at 14/22 Barton but potentially shaded by the proposed development at Part 3/22 Barton.

Twenty-four, 1 m^2 quadrats were established across the site at the beginning of the year 1 baseline survey season (RJPL 2014b). Each of these locations was approximately relocated using GPS locations and the map provided in the monitoring plan (RJPL 2014a). Plots were marked using wire pegs and plastic tags installed flush with the ground to permit relocation of the quadrats for repeat sampling during the season. All plot markers were removed at the end of the season.

2.3 GSM Flying Surveys

As specified in the monitoring plan (RJPL 2014a) flying GSM surveys were conducted in a manner consistent with the ACT Government (2010a) GSM survey guidelines and with the annual monitoring approach presented in Umwelt (*in prep*), as follows:

- Flying GSMs would be counted along two 100 m transects along the long axis of York Park (Figure 1) and recorded as number of GSM per 100 m transect.
- The transect survey would be undertaken three times approximately half an hour apart.
- To compare baseline GSM activity levels with post-shading GSM activity levels, two sets of rotational point counts, involving 10 repeated, 30 second rotational counts, would be conducted at one site in the centre of the York Park GSM site between the transect surveys (Figure 1). All GSM seen in a radius of 25 m are to be recorded. Any individuals that re-crossed the observer's visual path were double counted. Averages were calculated from the ten rotations at each point to provide number of GSM per 30 second rotation. Data recorded using this approach is comparable with data collected by Umwelt (Australia) Pty Ltd for the year 1 baseline surveys RJPL (2014b).
- To compare activity levels in the northern and southern ends of the York Park GSM site, two sets of rotational point counts, involving 10 repeated, 30 second rotational counts, would be conducted at two sites approximately one third and two thirds of the way along the centre line of York Park GSM site between the transect surveys (Figure 1), i.e. approximately 25 m from each end. All GSM seen in a radius of 25 metres are to be recorded. Any individuals that re-cross the observer's visual path would be double counted. Averages were calculated from the ten rotations at each point to provide a number of GSM per 30 second rotation.

The start of the GSM flying season was confirmed using known reference sites in the ACT, including York Park, and consultation with the ACT GSM monitoring group. In practice, suitable daily weather conditions determine repeat survey timings and shorter survey return times of no less than 3 days may be applied.

Other on-site weather data was recorded during all field surveys of flying GSM to assist with interpreting the GSM survey results on a year to year basis. The following data was recorded during flying moth surveys:

- wind speed and direction;
- air temperature; and
- cloud cover.

An additional three presence-absence surveys were conducted in early January to assist in assessing when the GSM flying season at York Park concluded. Each survey consisted of four transects through York Park undertaken over 20 to 30 minutes in suitable conditions.

2.4 Pupal Case Monitoring

Pupal case surveys were conducted as specified in the monitoring plan (RJPL 2014a). Pupal cases were counted in each of the 24 quadrat every two weeks over a six week period (i.e. 3 times) during the GSM flying period from early-to-mid November until late December. All cases detected were removed for identification (e.g. using microscopy). This would ensure that individual pupal cases were counted in one survey only.

2.5 Vegetation Monitoring

Data recorded for each quadrat included:

- all species present;
- the dominant species (single or multiple); and
- cover / abundance (%) using the Braun-Blanquet cover / abundance classes outlined in ACT Government (2010b).

Floristic value scores were calculated from abundance data based on Rehwinkel (2007) consistent with ACT Government (2010b).

2.6 Soil Temperature Monitoring

On-site soil temperature monitoring within shaded and un-shaded areas commenced on 9 May 2014. Temperature loggers were recovered and data downloaded on 16 October 2014.

2.7 Meteorological Data

No analyses or interpretation requiring the use of meteorological data from the Bureau of Meteorology are proposed prior to the 2015 flying season. Meteorological data from Canberra Airport for 2013 and 2014 would be obtained from the Bureau of Meteorology following the GSM flying season in 2015 to contribute to the first analyses of potential shading impacts. This will not have any effect on the content of the data. Data would subsequently be obtained annually to contribute to annual analyses.

3 RESULTS

3.1 Regional GSM Information

Data compiled by Conservation Planning and Research, ACT Government (CPR) indicated that GSM were first observed flying in the ACT on 4 November 2014 and were confirmed flying in moderate to high numbers at multiple sites in the ACT, including York Park, on 13 November 2014. The flying season was confirmed to have started throughout the region by the end of the second week of November 2014, had peak activity occurring around late November and had GSM activity continuing until early January 2015 (CPR, unpublished data). Low moth numbers were observed flying in York Park on 7 January 2015, but were not observed at York Park on 14 January 2015 or 20 January 2015 despite suitable weather conditions.

The last reported GSM observation for the season was on 8 January 2015 at Canberra Airport.

3.2 GSM Flying Surveys

Flying GSM were surveyed according to the method specified in the monitoring plan (RJPL 2014a) on three occasions approximately two weeks apart during the GSM flying period. Table 1 presents the dates and weather conditions of each survey. All surveys were conducted on suitable days. Other consultants and researchers also conducted surveys at various sites in the Canberra region and detected flying GSM (CPR, unpublished data).

Table 1. Site conditions during flying moth surveys.

Date	Max Temperature (ºC)	Rainfall (mm)	Wind speed and direction	Cloud cover
14/11/2014	33	0	12 km/h, W	Fine, thin high cloud
20/11/2014	27	0	7 km/h, W	Fine, thin high cloud
15/12/2014	28	0	8 km/h, W	Fine, no cloud

Appendix A presents the complete dataset for the flying moth surveys. Table 2 and Table 3 present aggregated survey results for transect surveys and rotational point counts respectively.

Table 2. Summary of flying GSM numbers - Transect surveys.

Transect	Transect location	Average (1dp)
Transect 1	East	13.5
Transect 2	West	8.5
Combined		11.0

Table 3. Summary of flying GSM numbers - Point count surveys.

Time	Location	Average (1dp)	Range
N/A	North	3.3	1 - 9
11:45	Centre	5.8	0 - 17
12:15	Centre	9.6	0 - 24
Centre Combined	Centre	7.7	0 - 24
N/A	South	3.1	1 - 7

Table 4. Site conditions and survey results during presence-absence surveys in January.

Date	Max Temperature (ºC)	Rainfall (mm)	Wind speed and direction	Cloud cover	GSM Present
07/01/2015	30	0 (Storm 48 hours before)	<10 km/h, W	Fine, scattered cloud	Present (3 male moths observed)
14/01/2015	30	0	<10 km/h, W	Fine, no cloud	Absent
20/01/2015	26	0 (Storm 36 hours before)	<10 km/h, W	Partly cloudy	Absent

Table 4 shows the results of presence – absence surveys for flying GSM conducted during January 2015. GSM were observed flying at York Park in low numbers in good conditions on 7 January 2015. Low-moderate numbers of flying GSM, and one female, were also incidentally observed in the median strip of Sydney Avenue to the east of York Park on 7 January 2015. No moths were observed in moderate to good conditions on 14 January 2015 or 20 January 2015.

3.3 Pupal Case Surveys

Pupal case surveys were conducted according to the method specified in the monitoring plan (RJPL 2014a) on three occasions two weeks apart. Surveys were undertaken on 20 November 2014, 2 December 2014 and 19 December 2014.

Appendix B presents the complete pupal case survey dataset. Table 5 presents a summary of the pupal case survey results for the control and impact zones. Low pupal case numbers were recorded, i.e. four pupal cases were recorded in Zone 1a and one pupal case was recorded in Zone 2a. No pupal cases were recorded in Zones 1b or 2b.

Table 5. Summary of the pupal case surveys within control and impact sites.

Zone	Pupal cases	
	Average (1dp)	Maximum number
Zone 1a	0.4	2
Zone 1b	0.0	0
Zone 1 (impact)	**0.3**	**2**
Zone 2a	0.1	1
Zone 2b	0.0	0
Zone 2 (control)	**0.1**	**1**

3.4 Vegetation Surveys

Dominant species, percentage cover and complete species lists, including Braun-Blanquet abundance scores, were collected for each quadrat. All data is presented in Appendix C. Species recorded are shown relative to the York Park GSM site cumulative species list of Rowell (2012) and RJPL (2014a), with a summary of the floristic value calculations for each quadrat. Table 6 presents a summary of the key vegetation quality indicators for the control and impact zones.

Table 6. Vegetation survey summary for the control and impact sites.

Zone	Floristic score		Native species	Exotic species	Cover (%)
	Average (1dp)	Maximum	Average Number (1dp)		Average
Zone 1a	1.0	4	5.8	8.2	85
Zone 1b	3.3	4	7.7	8.3	90
Zone 1 (impact)	**2.2**	**4**	**6.2**	**8.2**	**87**
Zone 2a	3.9	15	5.5	7.2	74
Zone 2b	4.0	6	4	9.3	72
Zone 2 (control)	**3.9**	**15**	**5.2**	**7.7**	**73**

3.5 Soil Temperature Monitoring

Soil temperature loggers were recovered on 17 October 2014. Data could not be downloaded in the field from the first logger recovered (Zone 1a) so all loggers were collected and returned to the office for testing. Three of the four loggers, from Zones 1b, 2a and 2b, were working correctly and data was successfully downloaded. These three loggers were returned to York Park on 21 October 2014.

The remaining logger, which had been located in Zone 1a, returned a fault and data could not be downloaded. The logger was returned to the factory but the data could not be recovered. The faulty logger was replaced under warranty and subsequently returned to York Park on 22 October 2014.

Due to the faulty logger, subsoil temperature data for further analysis is unavailable for Zone 1a. As loggers were retrieved for testing rather than immediately replaced in the soil, data recorded on the devices between 17 October 2014 and 22 October 2014 should also be excluded from analyses.

The maximum daily and minimum daily temperatures recorded by the loggers are presented in Appendix D. Table 7 presents the mean monthly temperature, mean maximum daily temperature and mean minimum daily temperature by month. Complete soil temperature data files are provided with this report.

Table 7. Soil temperature data recorded at York Park.

	Temperature (ºC)								
	Zone 1b			Zone 2a			Zone 2b		
Month	Mean	Mean Daily Max	Mean Daily Min	Mean	Mean Daily Max	Mean Daily Min	Mean	Mean Daily Max	Mean Daily Min
May (~23 days)	12.3	14.3	10.6	12.5	14.2	10.9	12.4	14.0	10.9
June	9.8	11.2	8.7	9.7	10.8	8.8	9.8	11.1	8.6
July	7.8	9.5	6.5	7.7	9.0	6.6	7.8	9.4	6.4
August	8.9	11.2	7.0	8.8	10.6	7.2	9.1	11.3	7.1
September	12.9	15.6	10.6	12.7	15.0	12.3	13.4	16.0	12.9
October (~16 days)	16.6	20.0	13.7	16.4	19.4	14.0	17.5	20.8	14.8

4 ECOLOGICAL INTERPRETATION

4.1 Ecological Interpretation

All flying moth surveys were undertaken during the peak period of GSM activity in the Canberra area and are consequently valid representations of GSM activity levels at the York Park GSM site. Flying moth numbers observed were consistently low to moderate during the surveys based on the semi-quantitative GSM site assessment method developed by David Hogg Pty Ltd (2010). Negligible difference was observed between GSM numbers observed during rotational point counts in the northern end and the southern end of York Park. In general marginally greater GSM numbers were observed along the eastern transect than along the western transect. Low to moderate GSM numbers are consistent with GSM populations present throughout large areas of GSM habitat within the ACT; although shared data available for regional GSM observations during the 2014 survey season does not provide sufficient information regarding survey effort to compare GSM activity levels between sites.

Five GSM pupal cases were recorded during the pupal case surveys; four cases in the impact zone and one in the control zone. This represents a very low rate of detection despite applying approximately six times the survey effort recommended by Richter (2013). Figure 2 shows quadrats in which pupal cases were detected. The pupal cases observed indicate that GSM are breeding within York Park, but the low number and scattered locations recorded do not permit any conclusions to be drawn as to whether GSM favour any part of York Park. These very low pupal case numbers are indicative of the challenges when conducting pupal surveys, e.g. pupal case distribution is highly variable and unpredictable.

Quadrats varied in floristic value, diversity, vegetation cover and weed presence, but overall were indicative of partially degraded natural temperate grassland. Vegetation in five quadrats within each of the control and impact zones (Figure 2) had a floristic score of four or greater, nominally meeting the criteria of Rehwinkel *et al.* (2007) for inclusion in the natural temperate grassland endangered ecological community. Floristic scores within the control zone were generally marginally greater, as indicated by the slightly higher average floristic score. Sites in the impact zone had marginally higher native and exotic species diversity, and slightly higher vegetation cover.

Overall, the year 2 baseline surveys demonstrate that GSM are present in low to moderate numbers at the York Park GSM site, with pupal cases detected at very low numbers, within both the control and impact areas. Vegetation surveys confirmed that the York Park GSM site supports partially degraded natural temperate grassland, the majority of which is potential GSM breeding habitat.

The last GSM observations during the 2014-15 flying season were recorded at York Park and the Canberra Airport on 7 January 2015 and 8 January 2015 respectively. The GSM flying season was effectively concluded by the week commencing 12 January 2014, with no observations recorded in the Canberra region after this date.

4.2 Comparison with Year 1 Baseline Data

Flying moths numbers during the 2014 flying season were consistently higher than during the 2013 flying season for both transects and the centre point survey (Figure 3, RJPL 2014b). The average moth number per transect was 4.4 moths during the 2013 survey (RJPL 2014b) and 11.0 moths during the current survey (Table 2). Similarly, the combined average moth number at the central point was 0.9 during the 2013 flying season (RJPL 2014a) compared with 7.7 during the current survey (Table 3). As the surveys were conducted at similar points during the season, and conditions were generally comparable, it is likely that this variation is due to natural seasonal variation in GSM activity. This observation is consistent with evidence that GSM activity levels may be highly variable even when conditions are favourable (Hogg 2010).

Three times as many pupal cases were detected during the current survey as in the 2013 season (Figure 4, RJPL 2014b). At the low rates of detection recorded, it is likely that the variation in pupal case detection between years and between the control and impact sites is due to stochastic variation. No conclusions can be drawn from the baseline data regarding the breeding success in the control and impact zones prior to any shading occurring.

Figure 5 and Figure 6 summarise vegetation survey results compared by year for the impact and control zones. The higher average floristic value scores and marginally higher diversity of both exotic and native species recorded during the vegetation assessment can be attributed to the survey timing. Surveys conducted for the 2014 season were undertaken in October and favour the detection of native forbs and exotic annuals more so than the surveys conducted in December for the 2013 season (RJPL 2014b). As anticipated prior to any impact occurring, the variation in results between years was consistent between the control and impact zones. Two additional sites in both the control and impact zones met criteria for consideration as natural temperate grassland based on the floristic score.

5 COMPLIANCE WITH THE GSM MONITORING PLAN

5.1 Survey Requirements

Transect surveys, pupal case surveys and vegetation surveys were conducted according to the methods specified in the monitoring plan (RJPL 2014a).

As described in Section 3.5, the soil temperature logger located in Zone 1a failed and data could not be recovered from the device. On recovery and detection of the fault, the soil temperature logger was replaced. Comparison of soil temperature data from the three functioning loggers indicates that there was minimal soil temperature variation across York Park, with average daily variation typically within the 0.5ºC error of the loggers.

For future analyses, data for Zone 1a for the period between 9 May 2014 and 17 October 2014 should be inferred from Zone 1b, as the logger in Zone 1b was closest to the logger in Zone 1a and conditions, including shading conditions, would have been almost identical during the period that data was lost. As the data was baseline data and collected prior to any shading of the York Park site by the proposed development, it is reasonable to use data from the nearest data logger in Zone 1b.

As comparably data is readily available to be used in place of the lost data, and the logger was replaced on detection of the fault, RJPL does not consider that the logger fault represents a compliance issue in relation to the approval and no further action is required.

5.2 Reporting Requirements

The GSM monitoring plan (RJPL 2014a) requires that annual monitoring reports meet the following specifications:

> Annual monitoring and compliance reports would be prepared in a timely manner (e.g. February for the annual monitoring report) each year meeting the *EPBC Act* approval requirements (Conditions 3, 8) by:
>
> - providing and assessing the monitoring data for the previous twelve months against the baseline conditions;
> - concluding whether or not there has been a decline in the population of GSM within the area of York Park shaded as a result of the action, taking into account regional population trends and local ecological conditions; and

- reviewing the GSMMP's applicability in achieving its objectives (Condition 8) to determine whether, under *EPBC Act* approval Condition 10, the GSMMP should be revised in consultation with the Commonwealth.

  When preparing the report, reference would be made to the current NTGMP and any relevant management and monitoring changes relevant to a review of this GSMMP.

The current report represents the second baseline data monitoring report. The above requirements for analysis against the baseline conditions and assessment of whether there has been a decline in the population of GSM at York Park do not yet apply.

The preparation of this report fulfils the reporting requirements for year 2 baseline surveys as specified in the monitoring plan (RJPL 2014a).

6 CONCLUSION

This report provides baseline results of flying moth surveys, pupal case surveys and vegetation surveys for 2014 in accordance with the *Potential shading impacts on York Park golden sun monitoring plan* (RJPL 2014a, the monitoring plan). Data is provided in summarised form suitable for incorporation into future analyses of potential impacts. Appendices A to D present all survey data.

The surveys confirmed the presence of GSM at low to moderate activity levels within the York Park GSM site, confirmed the low pupal case detection rates and confirmed the vegetation classification within the York Park GSM site as natural temperate grassland. Vegetation condition was generally consistent between the control and impact zones although variation was present between quadrats.

Soil temperature loggers were recovered and data downloaded from three of the four zones. The logger located in Zone 1a was faulty and replaced. Analysis of data from the three zones recorded indicates a low level of variation between loggers and the data recorded at the closest logger to Zone 1a, i.e. Zone 1b, can consequently be used as the baseline data for the period data is missing for Zone 1a in future analyses.

Detailed data analysis was not undertaken, as 2014 represents the second year of baseline data collection and no winter shading of the York Park GSM site has occurred. Basic data comparison with the first year of baseline data (RJPL 2014b) indicated that there is a high level of seasonal variability in the levels of GSM activity detected and a moderate level of variability in vegetation condition.

Surveys were conducted in a manner consistent with the survey requirements outlined in the monitoring plan (RJPL 2014a). This report also fulfils requirements for reporting the year 2 baseline monitoring data outlined in the monitoring plan (RJPL 2014a).

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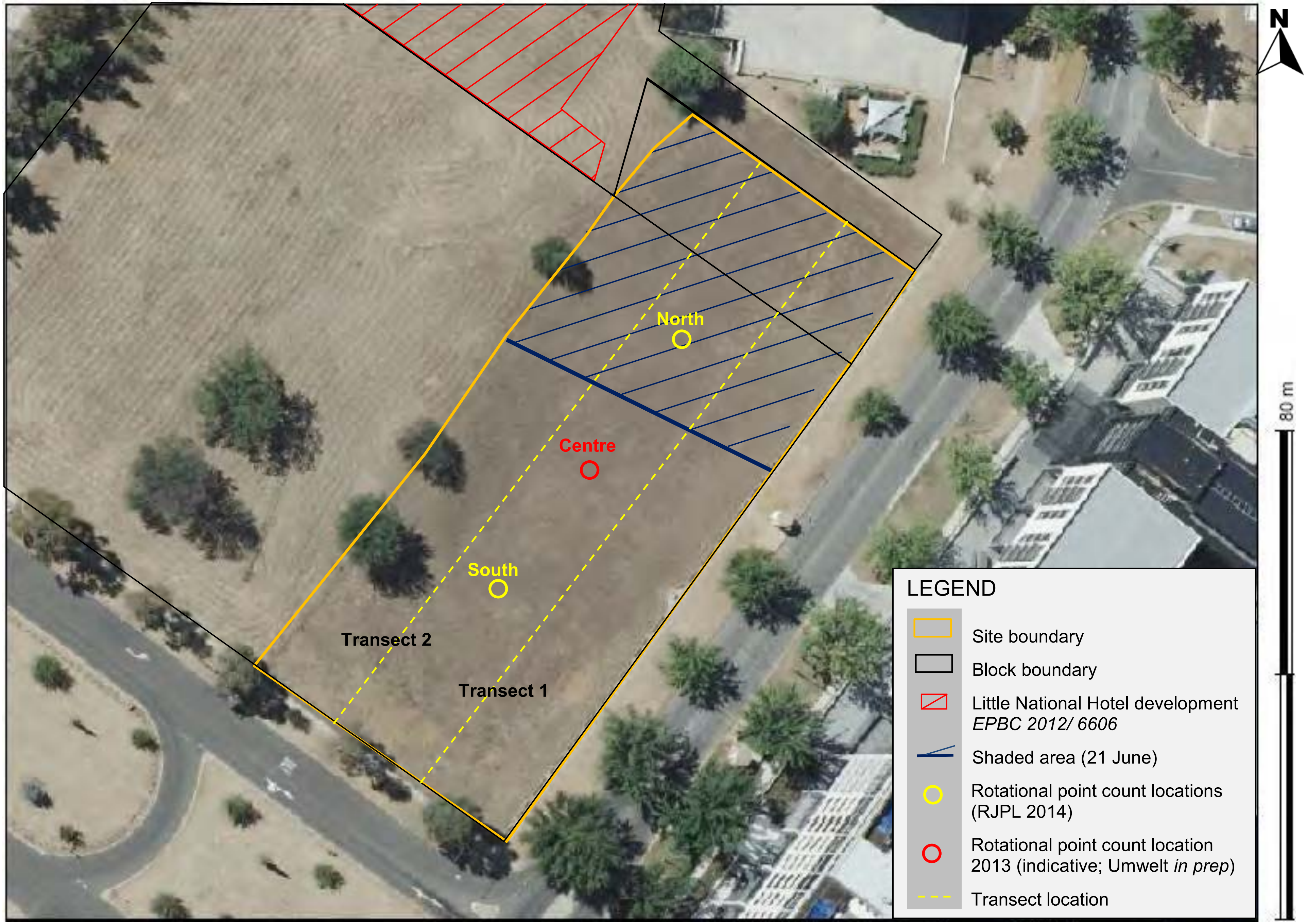

Figure 1. York Park GSM site flying moth survey details 2014.

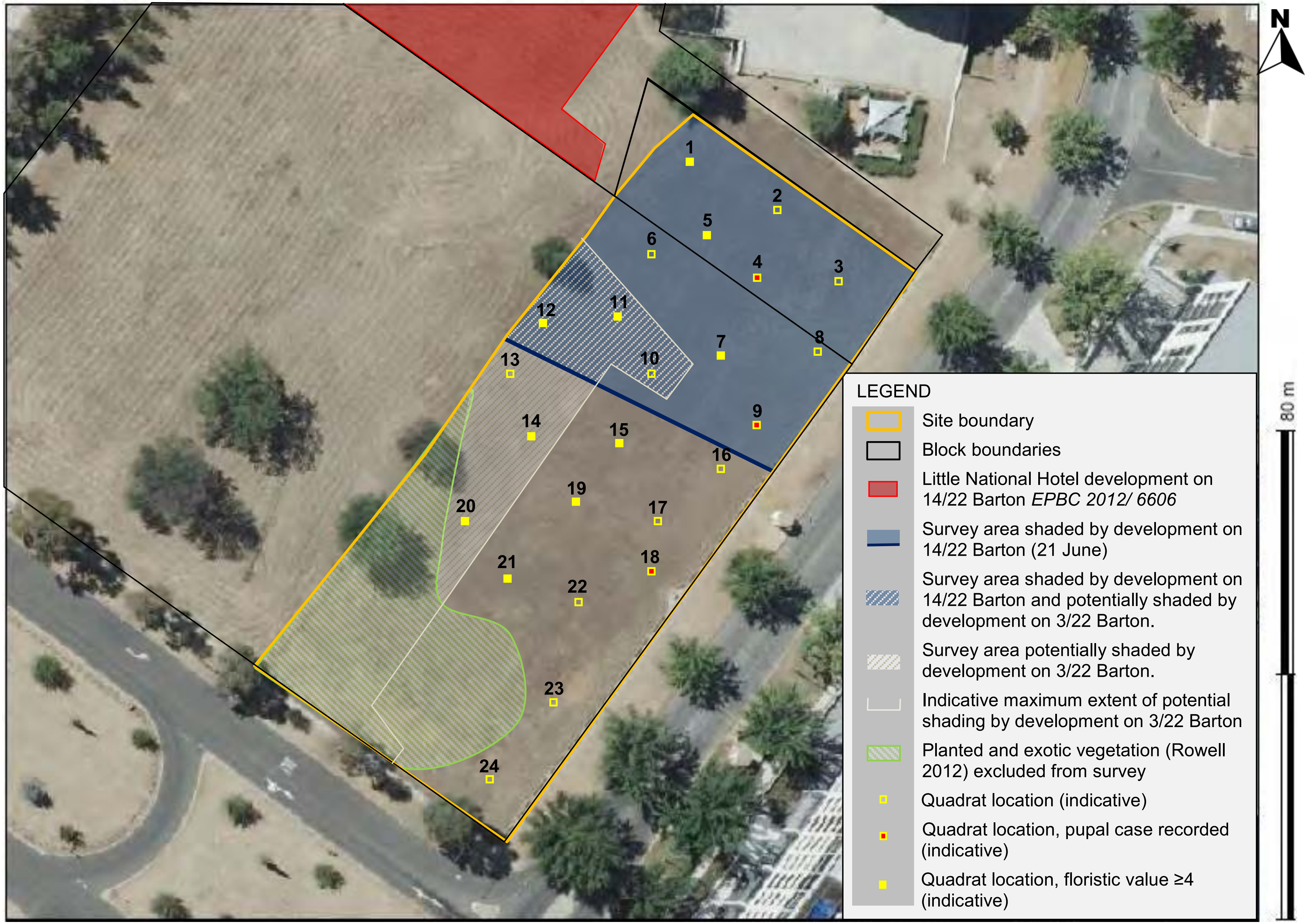

Figure 2. York Park GSM site pupal case and vegetation survey summary.

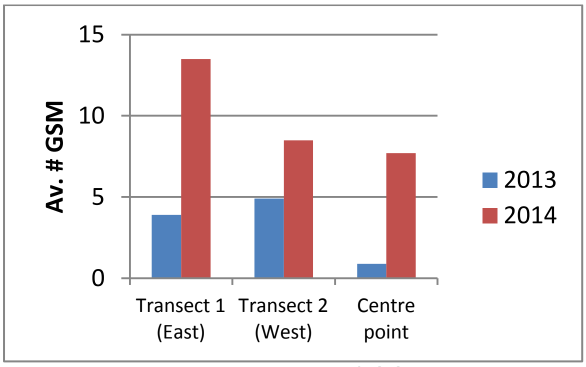

Figure 3. Average number of GSM observed.

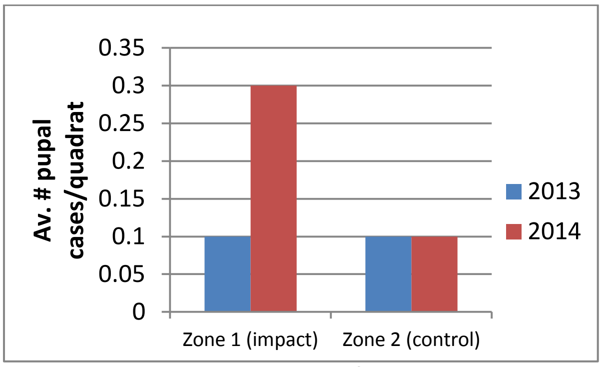

Figure 4. Average number of pupal cases observed.

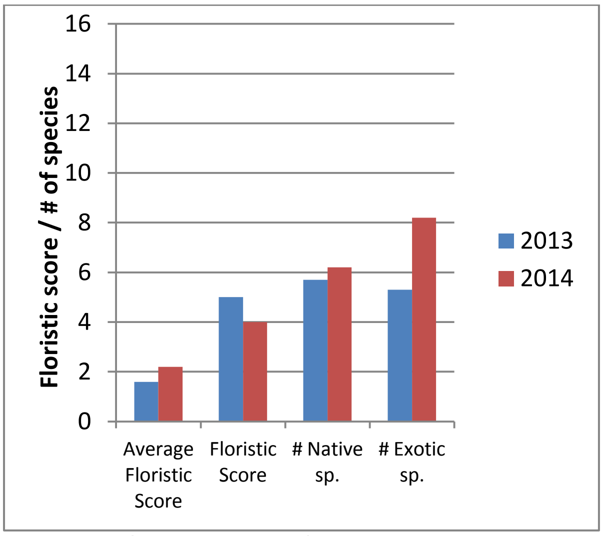

Figure 5. Comparison of impact zone vegetation statistics by year.

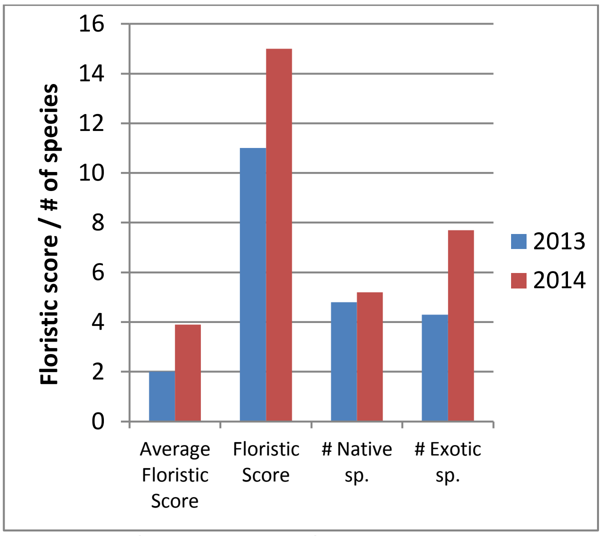

Figure 6. Comparison of control zone vegetation statistics by year.

APPENDICES

APPENDIX A – FLYING MOTH SURVEY 2014

Appendix A - Table 1: Flying moth surveys 2014 – transects.

Date	Transect	Moth numbers / Survey time			Moth numbers
		1130	1200	1230	Average (1dp)
14/11/2013	Transect 1	5	25	15	10.3
20/11/2013	Transect 1	12	25	30	22.3
15/12/2013	Transect 1	7	6	11	8.0
14/11/2013	Transect 2	4	5	3	4.0
20/11/2013	Transect 2	8	23	21	17.3
15/12/2013	Transect 2	3	6	4	4.3

Appendix A - Table 2: Flying moth surveys 2014 – point observations.

Date	Time	Point	Moth numbers	
			Average (1dp)	Range
14/11/2013	11:30	North	2.3	1-3
20/11/2013	11:40	North	5.5	1 - 9
15/12/2013	11:50	North	2.0	1 - 4
14/11/2013	11:43	Centre	6.8	3 - 10
20/11/2013	11:36	Centre	8.8	4 - 17
15/12/2013	11:38	Centre	1.8	0 - 4
14/11/2013	12:15	Centre	8.1	4 - 15
20/11/2013	12:36	Centre	18.8	16 - 24
15/12/2013	12:09	Centre	2.0	0 - 5
14/11/2013	11:55	South	3.0	1 - 6
20/11/2013	12:05	South	4.1	2 - 7
15/12/2013	12:20	South	2.3	1 - 4

APPENDIX B – PUPAL CASE SURVEY 2014

Date	Survey	Quadrat	Control or Impact site	Zone	Pupal case numbers	Notes
20/11/2013	1	1	Impact	1a	0	
20/11/2013	1	2	Impact	1a	0	
20/11/2013	1	3	Impact	1a	0	
20/11/2013	1	4	Impact	1a	0	*Delma inornata in plot*
20/11/2013	1	5	Impact	1a	0	
20/11/2013	1	6	Impact	1a	0	
20/11/2013	1	7	Impact	1a	0	
20/11/2013	1	8	Impact	1a	0	
20/11/2013	1	9	Impact	1a	0	
20/11/2013	1	10	Impact	1b	0	
20/11/2013	1	11	Impact	1b	0	
20/11/2013	1	12	Impact	1b	0	
20/11/2013	1	13	Control	2b	0	
20/11/2013	1	14	Control	2b	0	
20/11/2013	1	15	Control	2a	0	
20/11/2013	1	16	Control	2a	0	
20/11/2013	1	17	Control	2a	0	
20/11/2013	1	18	Control	2a	0	
20/11/2013	1	19	Control	2a	0	
20/11/2013	1	20	Control	2b	0	
20/11/2013	1	21	Control	2a	0	
20/11/2013	1	22	Control	2a	0	
20/11/2013	1	23	Control	2a	0	
20/11/2013	1	24	Control	2a	0	
2/12/2013	2	1	Impact	1a	0	
2/12/2013	2	2	Impact	1a	0	
2/12/2013	2	3	Impact	1a	0	
2/12/2013	2	4	Impact	1a	1	*Delma inornata skin*
2/12/2013	2	5	Impact	1a	0	
2/12/2013	2	6	Impact	1a	0	
2/12/2013	2	7	Impact	1a	0	
2/12/2013	2	8	Impact	1a	0	
2/12/2013	2	9	Impact	1a	2	
2/12/2013	2	10	Impact	1b	0	
2/12/2013	2	11	Impact	1b	0	
2/12/2013	2	12	Impact	1b	0	
2/12/2013	2	13	Control	2b	0	
2/12/2013	2	14	Control	2b	0	
2/12/2013	2	15	Control	2a	0	
2/12/2013	2	16	Control	2a	0	
2/12/2013	2	17	Control	2a	0	

Date	Survey	Quadrat	Control or Impact site	Zone	Pupal case numbers	Notes
2/12/2013	2	18	Control	2a	1	Possibly fragments of 2 pupae case, 1 confirmed.
2/12/2013	2	19	Control	2a	0	
2/12/2013	2	20	Control	2b	0	
2/12/2013	2	21	Control	2a	0	
2/12/2013	2	22	Control	2a	0	
2/12/2013	2	23	Control	2a	0	
2/12/2013	2	24	Control	2a	0	
19/12/2013	3	1	Impact	1a	0	
19/12/2013	3	2	Impact	1a	0	
19/12/2013	3	3	Impact	1a	0	
19/12/2013	3	4	Impact	1a	1	
19/12/2013	3	5	Impact	1a	0	
19/12/2013	3	6	Impact	1a	0	
19/12/2013	3	7	Impact	1a	0	
19/12/2013	3	8	Impact	1a	0	
19/12/2013	3	9	Impact	1a	0	
19/12/2013	3	10	Impact	1b	0	
19/12/2013	3	11	Impact	1b	0	
19/12/2013	3	12	Impact	1b	0	
19/12/2013	3	13	Control	2b	0	
19/12/2013	3	14	Control	2b	0	
19/12/2013	3	15	Control	2a	0	
19/12/2013	3	16	Control	2a	0	
19/12/2013	3	17	Control	2a	0	
19/12/2013	3	18	Control	2a	0	
19/12/2013	3	19	Control	2a	0	
19/12/2013	3	20	Control	2b	0	
19/12/2013	3	21	Control	2a	0	
19/12/2013	3	22	Control	2a	0	
19/12/2013	3	23	Control	2a	0	
19/12/2013	3	24	Control	2a	0	

APPENDIX C – VEGETATION SURVEY 2014

Appendix C - Table 1: Vegetation structure 2014.

Date	Quadrat	Control or Impact site	Zone	Species (* - exotic species)		Cover (%)
				Dominant	Co-Dominant	
16/10/2014	1	Impact	1a	*Austrostipa bigeniculata*	*Dactylis glomerata**	95
16/10/2014	2	Impact	1a	*Austrostipa bigeniculata*	*Hypochaeris radicata**	100
16/10/2014	3	Impact	1a	*Nassella neesiana*		80
16/10/2014	4	Impact	1a	*Austrostipa bigeniculata*		75
16/10/2014	5	Impact	1a	*Austrostipa bigeniculata*		85
16/10/2014	6	Impact	1a	*Austrostipa bigeniculata*		90
16/10/2014	7	Impact	1a	*Austrostipa bigeniculata*	*Nassella neesiana**	90
16/10/2014	8	Impact	1a	*Bothriochloa macra*		70
16/10/2014	9	Impact	1a	*Bothriochloa macra*		85
16/10/2014	10	Impact	1b	*Bothriochloa macra*	*Austrostipa bigeniculata*	100
16/10/2014	11	Impact	1b	*Austrostipa bigeniculata*	*Chrysocephalum apiculatum*	90
16/10/2014	12	Impact	1b	*Austrostipa bigeniculata*		80
16/10/2014	13	Control	2b	*Paspalum dilatatum**	*Austrostipa bigeniculata*	60
16/10/2014	14	Control	2b	*Austrostipa bigeniculata*		70
16/10/2014	15	Control	2a	*Austrostipa bigeniculata*		85
16/10/2014	16	Control	2a	*Bothriochloa macra*		80
16/10/2014	17	Control	2a	*Bothriochloa macra*		90
16/10/2014	18	Control	2a	*Bothriochloa macra*		85
16/10/2014	19	Control	2a	*Austrostipa bigeniculata*		80
16/10/2014	20	Control	2b	*Dactylis glomerata**		85
16/10/2014	21	Control	2a	*Austrostipa bigeniculata*		95
16/10/2014	22	Control	2a	*Paspalum dilatatum**	Bare	60
16/10/2014	23	Control	2a	*Cynodon dactylon**	Bare	40
16/10/2014	24	Control	2a	*Austrostipa bigeniculata*	50% litter	50

Appendix C - Table 2: Complete species list for the York Park GSM site (Rowell 2012); abundance scores for each species within quadrats.

Scientific name	Common name	Quadrat number																							
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Native grasses																									
Aristida ramosa	Wiregrass						+																		
Austrodanthonia auriculata	Lobed Wallaby Grass																								
Austrodanthonia bipartita	A Wallaby Grass																								
Austrodanthonia caespitosa	Ringed Wallaby Grass																								
Austrodanthonia carphoides	Short Wallaby Grass																								
Austrodanthonia fulva	A Wallaby Grass																								
Austrodanthonia laevis	Smooth Wallaby Grass																								
Austrodanthonia spp.	Wallaby Grasses	+				+	+		1	1	1	2	2		+	r	2	1	2	+		1	+		
Austrostipa bigeniculata	Tall Speargrass	3	3	2	3	2	2	2	1		2	2	2	2	2	2		1		3	2	3	+		3
Austrostipa densiflora	A Speargrass																								
Austrostipa scabra	Rough Speargrass																								
Bothriochloa macra	Redleg Grass	2	2	2	2	2	1	1	3	3	3	2	2	r	+	r	3	3	3	1	2	2	1		+
Chloris truncata	Windmill Grass																								
Elymus scaber	Wheatgrass	r								r	r											r			
Eragrostis brownii	A Lovegrass																								
Eragrostis trachycarpa	A Lovegrass																								
Microlaena stipoides	Weeping Grass								+				r	+											
Panicum effusum	Hairy Panic Grass	+	+			+						+	r			r		+							
Poa labillardieri	Tussock Grass																								
Themeda triandra	Kangaroo Grass								r																
Native forbs																									
Acaena ovina	Sheeps Burr																								
Asperula conferta[2]	Common Woodruff																					1			
Bulbine bulbosa[2]	Golden Lily	1									r	+									+	1			
Calocephalus citreus[2]	Lemon Beauty Heads														2										
Chamaesyce drummondii	Caustic Weed																								
Cheilanthes sp. [2]			r				r									+									
Cheilanthes sieberi[2]	Rock Fern																								
Cheilanthes tenuifolia[2]																									
Chenopodium pumilio	Small Crumbweed																								

Scientific name	Common name	Quadrat number																							
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Chrysocephalum apiculatum[1]	Yellow Buttons	2	2		r	1	1				r	2	2			2				1					
Convolvulus angustissimus	Australian Bindweed								r																
Crassula sieberiana	Australian Stonecrop																								
Cymbonotus lawsonianus	Bear's Ears																								
Drosera peltata	Sundew																								
Eryngium rostratum[2]	Blue Devil																					+			
Euchiton sp.	A Cudweed																								
Euchiton gymnocephalus	A Cudweed																								
Euchiton sphaericus	A Cudweed																								
Glycine tabacina[2]	Vanilla Glycine																								
Gonocarpus tetragynus[1]	Raspwort																								
Goodenia pinnatifida[2]	Scrambled Eggs														1	1					1	+			
Hypericum gramineum[2]	Small St John's Wort																								
Juncus sp.	A Rush																								
Lomandra bracteata[1]	A Matrush																								
Lomandra filiformis[1]	A Matrush		r			r	+	1			r					1				+		+			
Lomandra multiflora[2]	A Matrush																								
Lomandra sp. [1]	A Matrush																								
Microtis unifolia[2]	Common Onion Orchid															r									
Oxalis perennans	Soursob							r											r						
Pimelea curviflora[2]	Curved Rice-flower																								
Plantago varia[2]	Variable Plantain																								
Rumex brownii	Swamp Dock																								
Schoenus apogon	Bog-rush						r					r				r	r								
Sebaea ovata[2]																									
Senecio quadridentatus	Cotton Fireweed																								
Solenogyne dominii	Smooth Solenogyne																								
Stackhousia monogyna[2]	Creamy Candles																					r			
Tricoryne elatior[2]	Yellow Rush Lily					2		2					2			1				+					
Triptilodiscus pygmaeus[2]	Austral Sunray										r					+				r					
Vittadinia muelleri	Fuzzweed																								
Wahlenbergia sp.	A Bluebell				r	r	+		1	+	+					1	+		1	1		r			
Wahlenbergia communis	Tufted Bluebell																								

Scientific name	Common name	Quadrat number																							
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Wahlenbergia luteola	A Bluebell																								
Wahlenbergia stricta	Tall Bluebell																								
Wurmbea dioica[2]	Early Nancy																								
Xerochrysum viscosum[2]	Sticky Everlasting																								
Exotic grasses																									
Aira sp.	A Hairgrass	+	+			1	+	+		1	+	+	1	2	1	+	+	1	+	+	1	+			
Aira elegantissima	A Hairgrass																								
Avena sp.	Wild Oats	+	+		+	+	+	+				r	+								2	r	+	2	r
Avena barbata	Bearded Oats																								
Briza maxima	Blowfly Grass		1	2		+	+	1	+	1	+	+	r	1	+	+		1	r	+	+	+	r		
Briza minor	Shivery Grass	+	+		1	+						r							+	r					
Bromus sp.	A Brome Grass																								
Bromus catharticus	A Brome Grass																								
Bromus diandrus	A Brome Grass																								
Bromus hordeaceus	A Brome Grass																								
Bromus mollis	Soft Brome																								
Cynodon dactylon	Couch																								
Dactylis glomerata	Cocksfoot	3	+	1		r	r				r	r	+	1	r			2	+		2		+	2	
Eleusine tristachya	Goose Grass																								
Eragrostis curvula	African Lovegrass																								
Festuca sp.	A Fine-leaved Fescue																								
Festuca arundinacea	Tall Fescue																				+				
Lolium perenne	Perennial Ryegrass																								
Lolium rigidum	Ryegrass																								
Lophochloa cristata	Annual Cat's Tail																								
Nassella neesiana	Chilean Needlegrass			2				2															+		
Nassella trichotoma	Serrated Tussock																								
Paspalum dilatatum	Paspalum			2									2										2		
Phalaris aquatica	Phalaris																								
Poa bulbosa	Bulbous bluegrass	r																							
Vulpia sp.	Rat's-tail Fescue	1		1	1	1	+	+	+	1			1	1	+	+	2	1	+	+	+		1		
Exotic forbs																									
Acetosella vulgaris	Sorrel																								

Scientific name	Common name	Quadrat number																							
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Anagallis arvensis	Scarlet Pimpernel													r											
Arctotheca calendula	Capeweed																	r							
Centaurium erythraea	Pink Stars			1	+		+	+	+	1	+	1	+		+	+	+	1		+	+	1			
Cerastium glomeratum	Chickweed																								
Cirsium vulgare	Spear Thistle																								
Conyza bonariensis	Flax-leaf Fleabane																								
Echium plantagineum	Paterson's Curse																								
Erodium cicutarium	Common Crowfoot			1																					
Galium divaricatum	A Bedstraw																								
Gamochaeta purpurea	A Cudweed																								
Gnaphalium sp.	A Cudweed																								
Hirschfeldia incana	Hoary Mustard																								
Hypericum perforatum	St John's Wort				+	1							r		r								1		
Hypochaeris glabra	Smooth Catsear					+	+		r		+		+	1	r		r	1	r	r		+	r		
Hypochaeris radicata	Catsear	1	2	+	1	+	1	1	r		+	1				2		r		2				r	+
Lactuca serriola	Prickly Lettuce																				r				
Lepidium africanum	A Peppercress																								
Parentucellia latifolia	Common Bartsia									+					1		r	1			+				
Petrorhagia nanteulii	Proliferous Pink																								
Plantago lanceolata	Ribwort Plantain	1	+	+	r	+	+	2	+	2	+	1	+	2	1		2	2	2	+	2	2	2		
Romulea rosea	Onion Grass								1								+								
Salvia verbenaca	Wild Sage																								
Silene gallica	French Catchfly																								
Sonchus oleraceus	Common Sow-thistle										r														
Tragopogon porrifolius	Salsify																								
Trifolium angustifolium	Narrow leaf Clover																								
Trifolium arvense	Haresfoot Clover			+					1	1							r	r	+						
Trifolium campestre	Hop Clover		r							r									r			1			
Trifolium dubium																									
Trifolium glomeratum	Clustered Clover																								
Trifolium striatum																									
Trifolium spp.	Clovers			+					+								r	r	r						
Exotic shrubs and trees																									

Scientific name	Common name	Quadrat number																							
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Cotoneaster sp.	Cotoneaster																								
Crataegus monogyna	Hawthorn																								
Ligustrum sinense	Small-leaved Privet																								
Populus nigra var. *italica*	Lombardy Poplar																								
Prunus sp.	Plum																								
Sorbus domestica	Service Tree																								

[1]*Indicator species level 1,* [2]*Indicator species level 2*

Appendix C - Table 3: Summary of floristic score metrics 2014.

Indicator	Quadrat number																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Number of common species	5	3	2	3	5	6	3	7	4	5	5	5	3	3	7	4	4	4	4	2	5	3	0	2
Number of indicator level 1 species	1	2	0	1	2	2	1	0	0	2	1	1	0	0	2	0	0	0	2	0	1	0	0	0
Number of indicator level 2 species	1	1	0	0	1	1	1	0	0	2	1	1	0	2	5	0	0	0	2	2	5	0	0	0
Total number of native species	7	6	2	4	8	9	5	7	4	9	7	7	3	5	14	4	4	4	8	4	11	3	0	2
Number of exotic species	8	8	9	7	10	9	7	8	8	8	8	9	8	8	6	7	12	9	7	12	7	11	4	2
Number of significant weed species	0	0	1	1	1	0	1	0	0	0	0	1	0	1	0	0	0	0	0	0	0	2	0	0
Site value score	4	2	0	0	4	3	4	0	0	2	4	4	0	6	15	0	0	0	6	6	14	0	0	0

APPENDIX D – DAILY MAXIMUM AND MINIMUM SOIL TEMPERATURES

#*No data is provided for Zone 1a as the logger was faulty and no data could be recovered. No shading impacts occurred due to the development of the Little National Hotel during the period data was lost. For future analyses, data for Zone 1a should be inferred from Zone 1b, as the logger in Zone 1b was closest to the logger in Zone 1a and conditions, including shading conditions, would have been almost identical during the period that data was lost.*

Date	Temperature (ºC)					
	Zone 1b#		Zone 2a		Zone 2b	
	Daily Min	Daily Max	Daily Min	Daily Max	Daily Min	Daily Max
9-May-14	11.12	-	11.64	-	11.59	-
10-May-14	10.62	12.62	11.14	13.14	11.09	12.59
11-May-14	11.62	15.63	12.14	15.65	12.09	15.10
12-May-14	10.62	15.13	11.14	15.15	11.09	14.60
13-May-14	10.11	14.63	10.13	14.65	10.09	13.60
14-May-14	9.61	14.13	9.63	14.14	10.09	13.60
15-May-14	9.11	14.13	9.63	14.14	9.58	13.09
16-May-14	9.61	14.13	9.63	14.14	9.58	13.60
17-May-14	9.61	13.62	10.13	13.64	10.09	13.09
18-May-14	10.11	13.62	10.13	13.64	10.59	13.09
19-May-14	10.62	14.63	10.64	14.65	10.59	14.10
20-May-14	10.62	14.13	10.64	14.14	11.09	13.60
21-May-14	10.62	14.63	10.64	14.65	11.09	14.10
22-May-14	10.11	14.63	10.64	14.65	10.59	13.60
23-May-14	11.12	15.13	11.64	14.65	11.59	15.10
24-May-14	12.12	14.63	12.64	14.65	12.59	15.10
25-May-14	11.12	14.63	11.14	14.14	11.09	15.10
26-May-14	11.62	15.63	12.14	15.15	12.09	15.60
27-May-14	12.12	14.63	12.14	14.14	12.59	14.60
28-May-14	11.62	13.12	11.64	13.14	11.59	13.09
29-May-14	10.11	14.13	10.64	13.64	10.09	14.10
30-May-14	10.11	13.62	10.13	13.14	9.58	13.60
31-May-14	10.62	13.62	10.64	13.14	10.59	14.10
1-Jun-14	12.12	12.62	12.14	12.64	12.09	13.09
2-Jun-14	11.62	13.12	11.64	13.14	11.59	13.60
3-Jun-14	11.12	12.62	11.14	12.64	11.09	12.59
4-Jun-14	10.62	13.12	10.64	12.64	10.59	13.09
5-Jun-14	11.12	14.13	11.14	13.64	11.09	14.10
6-Jun-14	10.11	13.62	10.64	12.64	10.59	13.60
7-Jun-14	8.11	12.12	8.63	11.64	8.08	12.09
8-Jun-14	8.11	11.62	8.13	10.64	7.58	11.09
9-Jun-14	8.61	11.12	8.63	10.64	8.08	11.09
10-Jun-14	8.61	11.62	8.63	11.14	8.08	11.59
11-Jun-14	8.11	11.12	8.13	10.64	8.08	11.09

Date	Temperature (ºC)					
	Zone 1b#		Zone 2a		Zone 2b	
	Daily Min	Daily Max	Daily Min	Daily Max	Daily Min	Daily Max
12-Jun-14	8.11	11.12	8.13	10.64	8.08	11.09
13-Jun-14	8.11	10.11	8.13	10.13	8.08	10.09
14-Jun-14	10.11	12.62	10.13	12.14	10.09	12.59
15-Jun-14	9.11	12.62	9.63	12.14	9.58	12.59
16-Jun-14	8.11	11.12	8.63	10.64	8.08	11.09
17-Jun-14	8.61	11.62	9.13	11.14	8.58	11.59
18-Jun-14	8.61	11.12	8.63	10.64	8.58	11.09
19-Jun-14	8.11	10.62	8.13	10.13	8.08	10.59
20-Jun-14	8.11	11.12	8.63	10.64	8.08	11.09
21-Jun-14	7.10	10.62	7.12	10.13	7.08	10.59
22-Jun-14	7.10	11.12	7.63	10.13	7.08	10.59
23-Jun-14	8.11	9.11	8.13	9.13	8.08	9.08
24-Jun-14	7.60	8.61	7.63	8.63	7.58	8.58
25-Jun-14	7.60	9.61	7.63	9.13	7.58	9.58
26-Jun-14	8.11	10.62	8.13	10.13	8.08	10.09
27-Jun-14	8.61	10.62	8.63	10.13	8.58	10.59
28-Jun-14	7.60	8.61	7.63	8.63	7.08	8.58
29-Jun-14	7.60	8.11	7.63	8.13	7.08	8.08
30-Jun-14	6.60	9.11	6.62	8.63	6.07	9.08
1-Jul-14	5.59	9.11	5.62	8.63	5.57	8.58
2-Jul-14	6.60	8.11	6.62	8.13	6.07	8.08
3-Jul-14	7.10	9.61	7.12	9.13	7.08	9.58
4-Jul-14	7.10	10.11	7.12	9.13	6.57	9.58
5-Jul-14	6.60	9.61	6.62	9.13	6.57	9.58
6-Jul-14	7.10	9.61	7.12	9.13	7.08	9.58
7-Jul-14	6.10	9.61	6.12	9.13	6.07	9.58
8-Jul-14	6.10	9.61	6.62	9.13	6.07	9.08
9-Jul-14	5.59	7.10	5.62	7.12	5.57	7.08
10-Jul-14	6.10	8.61	6.12	8.13	6.07	8.58
11-Jul-14	6.60	9.61	7.12	9.13	6.57	9.58
12-Jul-14	6.60	9.11	7.12	8.63	7.08	9.08
13-Jul-14	5.09	8.61	5.12	8.13	4.57	8.58
14-Jul-14	4.59	8.61	4.61	8.13	4.57	8.58
15-Jul-14	7.10	8.11	7.12	8.13	7.08	8.58
16-Jul-14	8.11	9.61	8.13	9.63	8.08	10.09
17-Jul-14	8.11	10.11	8.13	9.63	8.08	10.59
18-Jul-14	6.60	9.61	6.62	9.13	6.57	9.58
19-Jul-14	5.59	9.11	5.62	8.63	5.07	8.58
20-Jul-14	4.59	9.11	5.12	8.13	4.57	8.58
21-Jul-14	5.09	9.11	5.12	8.13	5.07	8.58
22-Jul-14	6.60	10.11	6.62	9.63	6.57	10.09

Date	Temperature (ºC)					
	Zone 1b#		Zone 2a		Zone 2b	
	Daily Min	Daily Max	Daily Min	Daily Max	Daily Min	Daily Max
23-Jul-14	5.59	9.61	6.12	9.13	6.07	9.58
24-Jul-14	6.10	8.61	6.12	8.13	6.07	8.58
25-Jul-14	5.59	10.11	6.12	9.63	6.07	10.09
26-Jul-14	7.10	9.61	7.12	9.63	7.08	9.58
27-Jul-14	5.59	10.11	6.12	9.13	5.57	10.09
28-Jul-14	6.10	9.61	6.12	9.13	6.07	9.58
29-Jul-14	7.10	10.62	7.12	10.13	7.08	10.59
30-Jul-14	9.11	11.12	9.13	10.64	9.08	11.59
31-Jul-14	9.11	12.12	9.13	11.14	9.08	12.09
1-Aug-14	8.11	10.62	8.13	10.13	8.08	11.09
2-Aug-14	6.10	9.61	6.62	9.13	6.07	9.58
3-Aug-14	4.59	9.11	5.12	8.63	4.57	9.08
4-Aug-14	4.59	9.11	4.61	8.63	4.57	9.08
5-Aug-14	4.59	9.11	4.61	8.63	4.57	9.08
6-Aug-14	4.59	9.61	4.61	8.63	4.57	9.08
7-Aug-14	4.59	9.61	5.12	9.13	5.07	9.58
8-Aug-14	5.09	10.11	5.12	9.13	5.07	9.58
9-Aug-14	5.09	9.61	5.62	9.13	5.57	9.58
10-Aug-14	6.60	10.62	6.62	9.63	6.57	10.59
11-Aug-14	5.59	9.61	5.62	9.13	5.57	9.58
12-Aug-14	5.09	10.11	5.12	9.13	5.07	10.09
13-Aug-14	5.09	10.11	5.62	9.63	5.07	10.09
14-Aug-14	5.09	10.11	5.12	9.63	5.07	10.09
15-Aug-14	5.59	11.12	6.12	10.13	6.07	11.09
16-Aug-14	6.60	10.11	6.62	9.63	6.57	10.59
17-Aug-14	8.61	9.61	8.63	9.13	8.58	9.58
18-Aug-14	8.61	11.62	8.63	11.14	8.58	12.09
19-Aug-14	9.11	12.12	9.13	11.64	9.08	12.09
20-Aug-14	7.60	12.12	7.63	11.64	7.58	12.59
21-Aug-14	7.10	11.12	7.63	10.64	7.08	11.09
22-Aug-14	7.60	12.12	7.63	11.64	8.08	12.59
23-Aug-14	8.11	12.12	8.13	12.14	8.08	12.59
24-Aug-14	9.61	14.13	9.63	13.14	9.58	14.60
25-Aug-14	9.11	13.12	9.13	12.64	9.08	13.60
26-Aug-14	10.11	12.62	10.13	12.14	10.59	13.09
27-Aug-14	9.61	13.62	9.63	13.14	10.09	14.10
28-Aug-14	8.11	12.12	8.63	11.64	8.58	12.59
29-Aug-14	8.61	13.62	8.63	13.14	8.58	14.10
30-Aug-14	8.61	14.13	8.63	13.14	9.08	14.10
31-Aug-14	9.61	14.63	9.63	13.64	9.58	14.60
1-Sep-14	9.11	13.62	9.13	12.64	9.08	13.60

Date	Temperature (ºC)					
	Zone 1b#		Zone 2a		Zone 2b	
	Daily Min	Daily Max	Daily Min	Daily Max	Daily Min	Daily Max
2-Sep-14	9.61	12.12	10.13	11.64	10.09	12.09
3-Sep-14	8.11	12.12	8.13	11.64	8.58	12.59
4-Sep-14	7.60	12.12	7.63	12.14	7.58	12.59
5-Sep-14	8.61	13.12	8.63	12.64	9.08	13.09
6-Sep-14	8.11	12.12	8.63	12.14	8.58	12.59
7-Sep-14	7.60	14.13	8.13	13.14	8.08	14.10
8-Sep-14	9.11	14.63	9.13	14.14	9.58	15.10
9-Sep-14	10.11	13.62	10.13	13.14	10.59	14.10
10-Sep-14	11.62	15.63	11.14	14.65	11.59	16.10
11-Sep-14	10.11	14.63	10.64	14.14	10.59	15.60
12-Sep-14	10.11	14.13	10.64	13.64	10.59	14.60
13-Sep-14	11.12	15.13	11.64	14.65	11.59	15.10
14-Sep-14	10.11	15.63	10.13	15.15	10.59	16.10
15-Sep-14	10.62	16.13	10.64	15.15	11.09	16.60
16-Sep-14	12.12	16.13	12.14	15.65	12.59	17.10
17-Sep-14	11.62	15.63	11.64	15.15	12.09	16.10
18-Sep-14	10.11	15.13	10.13	14.65	10.59	15.60
19-Sep-14	9.11	15.63	9.13	14.65	9.58	15.60
20-Sep-14	9.61	16.13	9.63	15.15	10.09	16.10
21-Sep-14	11.62	16.63	11.64	16.15	12.09	17.10
22-Sep-14	12.62	18.63	12.64	17.65	13.09	18.61
23-Sep-14	12.12	18.63	12.14	17.65	12.59	19.11
24-Sep-14	12.12	16.63	12.14	16.15	12.59	17.10
25-Sep-14	13.62	17.13	13.64	16.65	14.60	17.60
26-Sep-14	11.62	17.13	11.64	16.65	12.09	17.60
27-Sep-14	12.12	18.13	12.14	17.65	13.09	18.61
28-Sep-14	12.12	19.13	12.14	18.15	12.59	19.61
29-Sep-14	13.12	19.64	13.14	19.15	14.10	20.61
30-Sep-14	13.12	19.64	13.14	18.65	14.10	20.61
1-Oct-14	12.62	19.13	12.64	18.65	13.60	20.11
2-Oct-14	12.12	19.13	12.14	18.15	13.09	20.11
3-Oct-14	12.12	20.14	12.64	19.15	13.60	20.61
4-Oct-14	15.13	21.64	15.15	20.66	15.60	22.11
5-Oct-14	13.62	21.14	14.14	20.66	15.10	22.11
6-Oct-14	15.13	22.14	15.15	21.66	16.10	23.11
7-Oct-14	16.13	21.64	16.15	20.66	17.10	23.11
8-Oct-14	13.62	20.14	14.14	19.66	15.10	21.11
9-Oct-14	13.62	21.14	14.14	20.16	14.60	22.11
10-Oct-14	13.62	19.64	13.64	19.15	14.60	20.61
11-Oct-14	13.62	22.14	14.14	21.16	15.10	23.11
12-Oct-14	14.13	22.64	14.65	21.66	15.60	23.61

Date	Temperature (ºC)					
	Zone 1b#		Zone 2a		Zone 2b	
	Daily Min	Daily Max	Daily Min	Daily Max	Daily Min	Daily Max
13-Oct-14	15.63	18.63	15.65	18.15	17.10	19.61
14-Oct-14	12.12	14.63	12.64	14.65	13.09	16.10
15-Oct-14	11.62	16.63	11.64	16.15	12.59	17.10
16-Oct-14	11.62	21.64	12.14	21.16	12.59	21.11
17-Oct-14	17.13	18.13	16.65	17.65	17.10	17.60

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Prepared for the Department of Finance and Deregulation, Canberra

Block 3, Section 22 Barton, ACT

Five-year monitoring event for Golden Sun Moth

and condition assessment of Natural Temperate Grassland

Report to Department of Finance and Deregulation

by

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May 2012

Summary of results and recommendations

A Golden Sun Moth (GSM) mark-release-recapture survey was carried out at Block 3 Section 22 Barton in December 2011. The amount of data collected was affected by adverse weather conditions and by the GSM flying season starting before the dates covered by the Permit to Take. The results suggest that numbers of GSM were lower at the site in 2011 than in previous years, which is similar to findings from other surveys in the district.

Vegetation mapping and survey was carried out between November 2011 and January 2012. This showed some changes in the Natural Temperate Grassland, including:

- Native plant diversity stable
- A decrease in bare ground and increase in vegetation density
- An increase in some weed species, and a decrease in others
- A minor decrease in Wallaby Grasses
- Expansion of Kangaroo Grass into GSM habitat.

The main recommendations include:

- Continuation of the GSM survey method, with mark-release-recapture sessions covering the whole GSM flying season
- More frequent mowing in wetter years
- Raking and removing slashed material when vegetation is long and weedy
- Carefully targeted chemical control of St Johns Wort and dense patches of exotic perennial grasses
- Replanting of poisoned patches of perennial exotic grasses with Wallaby Grasses
- Removal of deciduous trees from western boundary of site
- Containment of Kangaroo Grass to a 2 metre strip adjacent to National Circuit, poisoning of plants outside this area.

Block 3, Section 22 Barton, ACT:
Five-year monitoring event for Golden Sun Moth and condition assessment of Natural Temperate Grassland

1. Introduction

1.1 Background

The south-eastern part of Block 3 and eastern part of Block 7, Section 22 Barton ACT contain a population of Golden Sun Moth *Synemon plana*, in about 0.5 ha of Natural Temperate Grassland dominated by species of Wallaby Grasses (*Austrodanthonia*) (ACT Government 1997, 1998, 2005). This part of Barton is part of an area known as 'York Park'. This term is often also applied to the Golden Sun Moth GSM site on this block, and will be used in this report. Block 3 is owned by the Department of Finance and Deregulation and Block 7 is Territory land, but the GSM habitat is managed as one unit.

The Golden Sun Moth (GSM) is listed as Critically Endangered under Section 179 of the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999,* and Endangered (Section 21) of the ACT *Nature Conservation Act 1980.* Natural Temperate Grassland (NTG) is also listed as an endangered ecological community under both Acts. Nationally threatened species and communities are identified as Matters of National Environmental Significance under the *EPBC Act*. Any proposed action on or near a site, which may have a significant effect on such values, must be referred by the proponent to the Commonwealth Environment Minister, for assessment as to whether the action requires approval under the Act. As part of Master Planning for development of the part of Block 3 that does not contain GSM, the Department of Finance and Deregulation commissioned a Natural Temperate Grassland Maintenance Plan to protect the GSM and its Natural Temperate Grassland habitat (Parsons Brinckerhoff 2008).

1.2 Environmental values of the site

1.2.1 Natural Temperate Grassland

Status of the community

Natural Temperate Grassland of the Southern Tablelands of NSW and the Australian Capital Territory is listed as an endangered ecological community under the *EPBC Act*. The community is found between 560 and 1200 metres in valleys and broad plains. The dominant cover is native tussock grasses, with forbs such as daisies, lilies and native legumes in the intertussock spaces. It is estimated that about 5% of the original area of the community in the ACT survives in moderate to good condition, and up to about 1.5% remains in this condition over its whole previous range. Over 200 hectares of this community is reserved in the ACT, and about the same area is reserved in NSW (ESSS 2000).

Vegetation on the study site

In the *ACT Lowland Native Grassland Conservation Strategy* (ACT Government 2005) the grassland on the York Park site was given a Botanical Significance Rating of 4 (Low), and a Conservation Rating of 2 (Complementary Conservation Site). The Botanical Significance Rating system rates sites from Very Low (BSR 5) to Very High (BSR 1), taking into account native species diversity, the number of uncommon native species and the degree of weed invasion and other disturbance of the site. The Conservation Rating system puts sites into three categories. In descending order these are 1 (Core), 2 (Complementary) and 3 (Landscape and Urban). The Conservation Rating takes into account the BSR, size and shape of site, significance as threatened species habitat and connectivity with other native vegetation. The Conservation Rating of 2 reflects that the site is small and has only a low Botanical Significance, but contains a well-studied population of a threatened species that is considered to be viable in the medium term (ACT Government 1998 and 2005).

The Natural Temperate Grassland on this site is part of a long-term grassland monitoring program being undertaken by Environment ACT, and the vegetation quality in Block 3 has previously been assessed and mapped (Davis & Hogg 1992, ERM 2005).

1.2.2 Golden Sun Moth *Synemon plana*

Status of the species

The GSM is listed as Critically Endangered nationally, and Endangered in all the States and Territories in which it occurs. A Critically Endangered species is considered to be facing an extremely high risk of extinction in the wild in the immediate future.

Distribution

Prior to European settlement the species was widespread in native grasslands in south-eastern Australia (Edwards 1993, 1994). Its distribution was correlated with grasslands dominated by low-growing Wallaby Grasses (*Austrodanthonia* species), and has contracted substantially (O'Dwyer & Attiwill 1999). The species is now only found in a few relatively small breeding areas due to habitat loss, fragmentation and degradation. Possibly less than one percent of the original habitat now remains, much of it degraded by weed invasion (Clarke & O'Dwyer 1997, O'Dwyer & Attiwill 1999, ACT Government 2005).

Description and life history

The GSM is a medium sized day-flying moth in the family Castniidae. The male has a wingspan of about 34 mm, the female slightly less. The upper forewings of both are grey/brown with paler patterns. The male has dark brown upper hindwings, and in the female these are bright yellow/orange edged with black spots.

GSM larvae feed on the underground parts of Wallaby Grasses (Edwards 1993, O'Dwyer & Attiwill 1999) and some other native and introduced grasses (Braby & Dunford 2006, Richter *et al.* 2010). Larval development time (and thus generation time) appears to be longer than 12 months, as large and small larvae are present in the soil in spring (before emergence) and also in winter (Richter *et al* in prep.).

The adults live for only 1–2 (-4) days after emerging during spring, and do not feed as they have no functional mouth parts. In the middle of the day when conditions are sunny and warm, males patrol the grassland in search of the females, which have reduced hindwings and are poor fliers. The limited flight ability of the female moths makes the species vulnerable to extinction on small sites, and makes natural re-colonisation from other sites unlikely.

The starting date and duration of the flight season vary from year to year, probably depending on spring weather conditions, with the season starting earlier in a warm dry spring (Cook & Edwards 1993).

Golden Sun Moth population on the study site

The York Park site, although small, has received a Moderate Conservation Value rating (Section 1.2.1), because the previous scientific work on GSM carried out on the site enhances its value (ACT Government 1998). Clarke & O'Dwyer (1998) also considered that this site warranted special attention due to its 'high profile and considerable research focus in past years'.

The area of the GSM habitat on this site is about 5600m². The population has been intensively surveyed in the past. The previous studies include four mark-release-recapture surveys producing estimates of population size (Cook & Edwards 1993 & 1994, Harwood *et al.* 1995, Rowell 2007), and genetic analysis of the population (Clarke & O'Dwyer 1998).

As well as the 2008 Maintenance Plan, there were earlier management recommendations for GSM habitat on the site (Frawley 1995, Edwards 1995). These included rehabilitation of the vegetation at the Sydney Avenue end by translocation of soil and grassland plants from a nearby area which was being developed (Davis & Hogg 1992, Harwood *et al.* 1995).

2. The Brief

Finance requires an NTG condition assessment of Block 3, Section 22 Barton that maps the extent and condition of vegetation associations on the site and compares the results with the vegetation mapping conducted in 2007. The condition assessment is also to assess and comment on the composition of native flora species, status of exotic weeds, the effectiveness of weed control and biomass management in general.

Finance also requires a 5 yearly monitoring event for the GSM population on Block 3/Block7, Section 22 Barton using the nested sampling structure that is referred to in the Natural Temperate Grassland Maintenance Plan.

The York Park site includes ACT Government land (part Block 7), but the moths fly freely over the grassland and the habitat is continuous between the Commonwealth and ACT land. The survey was undertaken across both blocks, and there were communications with Dr Murray Evans of ACT Government in November and December 2011 before and during the mark-release-recapture survey.

2.1 Condition Assessment and Report for Block 3, Section 22, Barton

The assessment of NTG condition is to be carried out in Spring 2011 and is to include:

- recording all plant species on the subject site on a cumulative annual species list and undertaking a comparative analysis with previous assessments (as per the NTG Maintenance Plan) to measure changes in species richness and site condition over time
- mapping the vegetation associations across the site
- step-point transects and comparison to previous survey results
- quadrat assessment and comparison to previous survey results
- documenting any damage to the vegetation across the site
- assessing the status of exotic weeds across the site and the effectiveness of weed control measures to reduce exotic weed cover and manage biomass
- a photographic record from the points indicated in Figure 4.2 of the NTG Maintenance Plan to give a general indication of vegetation structure on various parts of the subject site.

2.2 Five-yearly GSM Monitoring Event and Report

Monitoring is to use the less invasive nested sampling structure recommended in the Natural Temperate Grassland Maintenance Plan for future GSM population estimation. This mark-release-recapture method allows population estimation without daily captures.

The survey report is to provide comparison to previous survey results, and allow for differences in survey methodology in comparing population estimates.

Mark-release-recapture surveys involve repeated handling of animals and require the prior issue of a Permit to Take by the Department of Sustainability, Environment, Water, Population and Community (SEWPaC).

3. Methods

3.1 Vegetation condition assessment

3.1.1 Species list

All plant species recorded on the site during the vegetation and GSM monitoring in spring/summer 2009 were added to the cumulative species spreadsheet which contains data from twelve previous surveys between 1991 and 2009 (Appendix 1). This list records changes in native species richness, and eradication or introduction of weed species.

3.1.2 Mapping of vegetation associations and quality

In the Maintenance Plan, the vegetation was mapped into associations reflecting vegetation quality. In January 2012 changes in the boundaries of these vegetation associations since 2007 were mapped to provide information on the effectiveness of the weed control program, and to show changes in grassland quality (Map 1).

3.1.3 Step-point transects

Two 100 metre step-point transects were surveyed along the long axis of the site in January 2012, recording the relative abundance of plant species and the amount of bare ground present by counting 'hits' on a vertical wire at each metre along a measuring tape. The results were entered in a cumulative spreadsheet containing records for the same transects from 2007 and 2009 (Appendix 2). This method is useful for measuring changes in the abundance of the dominant plant species and bare ground.

3.1.4 Quadrat assessment

A 20 x 20 metre standard grassland quadrat was surveyed in the same position as the 2006, 2007 and 2009 surveys, recording all plant species present and their percentage cover. The quadrat is near the centre of the site in high quality native grassland. The survey was undertaken in January (as in 2006 and 2009), when it is possible to identify the different species of Wallaby Grasses present. This is important information for assessment of GSM habitat. Any spring flowering species which might be missed by a summer quadrat survey are likely to be recorded during the GSM surveys which involve multiple visits between October and December. The data was entered in a cumulative spreadsheet for comparison with previous surveys (Appendix 3). A Floristic Value Score was calculated for the quadrat (Rehwinkel 2007). This is a quantitative method that uses the presence and abundance of uncommon and sensitive species to assess the relative quality of the vegetation. Reference photographs were taken from the same points as in 2007 and 2009 (Appendix 5). GSM pupal cases were searched for during the quadrat survey, which involves close inspection of 400 square metres of plants and bare ground.

3.2 Golden Sun Moth monitoring

3.2.1 Previous surveys

Previous population estimation surveys have involved daily capture of males (and females in some years) throughout the flying period. The impact of this on survival and breeding of GSM is not known, although numbers were not reduced when the procedure was carried out over three consecutive seasons in the 1990s, and the 2006 population estimate was comparable to the earlier years. However, it is a very intrusive procedure, and could be damaging to the population in years when numbers are already low for other reasons.

An alternative method using a nested sampling structure was used in 2011 (designed by Dr Anett Richter, University of Canberra, see below). It allows population estimation with less interference.

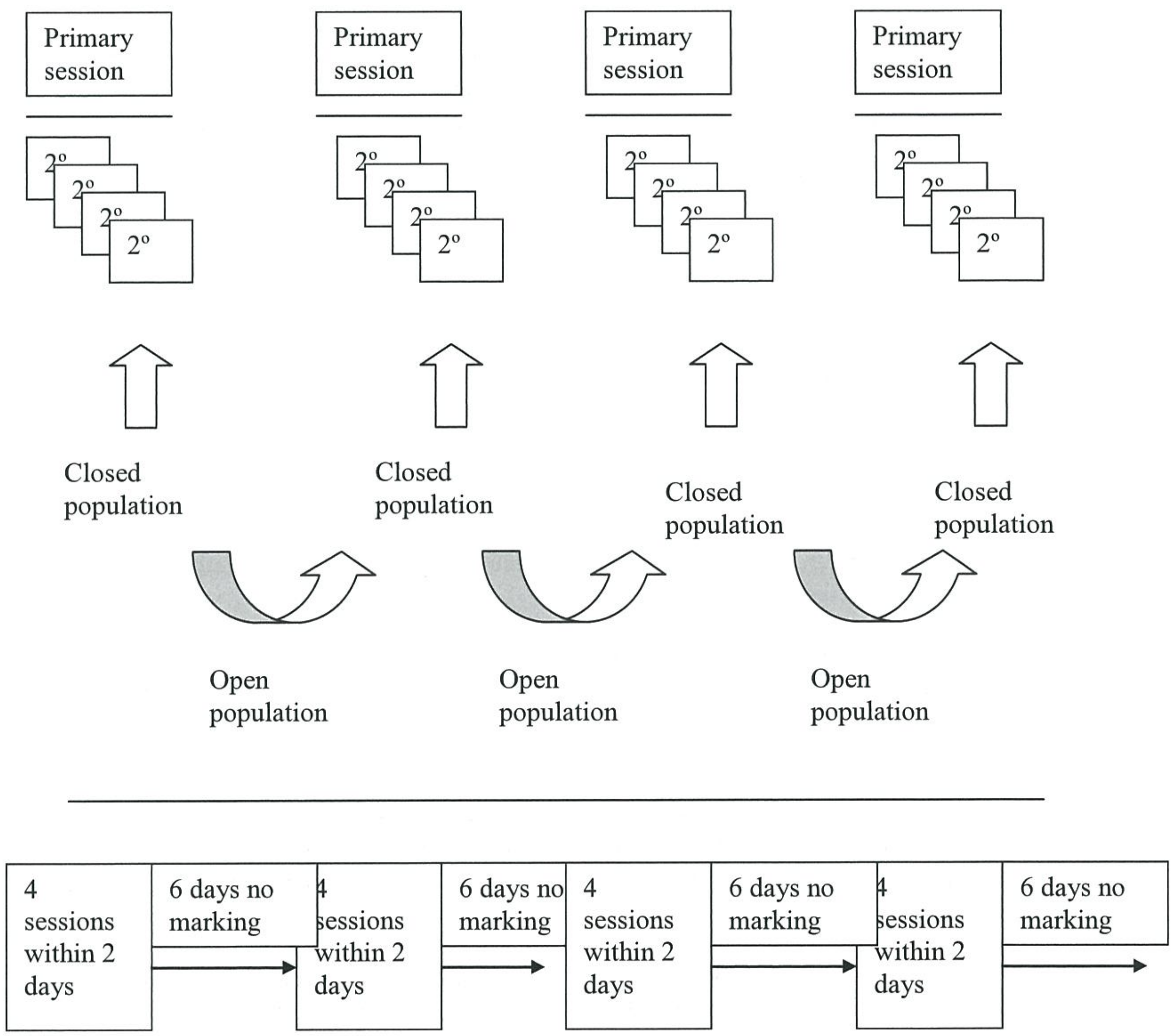
3.2.2 The Robust Design

This mark-release-recapture method allows population estimation without daily captures. It features a nested sampling structure, timed to take account of the short life-span of adult GSM (1-4 days). The first level consists of primary sampling sessions. The population experiences mortality (and potentially immigration) between primary sessions, allowing application of open population models. The secondary level of sampling involves a short mark-release-recapture study within each primary session. Closed population models are used at this stage to estimate the animal abundance at each primary session.

The timing of the primary and secondary sampling sessions depends on the biology of the study species. Due to the short life span of GSM (average less than 2 days), secondary sampling sessions need to take place within two days. To verify a closed population (no immigration, emigration, birth and deaths) four secondary sessions need to take place within two days (see design below).

Observational surveys of the Site should be undertaken weekly from late October to determine the beginning of the flying period. The first primary session should begin as soon as flying males are detected, and should be repeated every 8 days until there are no new captures.

Design of the Mark-Release-Recapture survey:



3.2.3 Timing of surveys in 2011

Several groups of local consultants shared information about the activity of GSM in the Canberra area this season. Surveyors were out looking for GSM most days (including weekends and public holidays) unless it was cold or raining. This enabled the start and end of the season to be pinpointed, and provided information about the response of GSM to local weather conditions.

A Permit to Take under Section 201 of the *EPBC Act 1999* was sought and obtained from the Department of Sustainability, Environment, Water, Population and Community (E2011-0062), and site visits began in late October. The first GSM of the 2011 season in the ACT were seen on several sites on 8 November, including one moth near (but not on) York Park. On 18 November low numbers were first seen flying at York Park, and at several other sites. The Permit to Take was signed on 29 November. GSM were active at York Park that morning, but there was a heavy storm that afternoon. Cool weather and further rain in the following week meant that the first primary session could not be undertaken until 9-10 December. This session was followed by more days of low temperatures and rain.

A second primary session was attempted on 16 December, but this was abandoned after only one GSM was captured in the first hour. More cool wet days followed, and the second primary session was carried out on 23-24 December.

The third primary session was attempted on 30 December, but was also abandoned after only one moth was captured and the weather deteriorated. This session was then undertaken on 31 December and 1 January. Despite good conditions on 1 January, no GSM were captured this day, and none were seen under suitable conditions on 4 and 7 January, indicating the end of the season at this site. GSM continued to fly in low numbers on other sites until 18 January, but it was noted that most records were from wetter areas of large sites.

In the period covered by the Permit, GSM were seen flying on 12 days in York Park, and surveys were attempted or completed on eight of those days.

3.2.4 Capture and marking

Two observers captured moths from all parts of the site with 40cm butterfly nets, and marked a number on the underside of the hindwing, using a quick-drying xylene-free metallic ink pen (Artline 999XF Silver). The mark number, location of capture and condition of each moth were recorded on a daily data sheet. After marking, moths were kept in the shade in a mesh-sided holding cage with a cloth cover, to reduce damage from fluttering. Moths were released in the centre of the site at the end of each collection period.

The first capture session each day was for one hour, between about 1045 and 1145 hours (Eastern Daylight Saving Time). Marked GSM were then released, and after 30 minutes the second capture session started, running from about 1215 to 1315 hours. This was repeated on the second day of each primary session, to give four secondary sessions.

4. Results

4.1 Vegetation condition assessment

3.1.1 Species list

The number of native grasses present was similar to or slightly higher than recent years. Four species of Wallaby Grass were recorded in 2011. There were more native forbs than any survey since 1992, which may be the result of germination of seed from the soil seed bank after two consecutive wet springs. There were 40 native species recorded, including nine 'sensitive' species (Indicator Species Level 2, Rehwinkel 2007).

The number of species of exotic grasses and forbs was not higher than recent years, but of concern was the reappearance of St Johns Wort and Flax-leaf Fleabane after one and seven years absence respectively. Two previously recorded serious weeds (Serrated Tussock and Paterson's Curse) were not seen on the site in 2011.

3.1.2 Mapping of vegetation associations and quality

The native-dominated vegetation (NTG) was mapped into high and lower diversity categories as in 2007 (Map 1). The dominant grasses were less clearly confined to one category, and the wetter years may have affected their distribution. The low diversity areas had greater than 50% native cover, mainly native grasses and a few common forb species, while the high quality areas had greater than 75% native cover, with a high diversity of forbs. The quadrat is in a high quality area.

Kangaroo Grass appears to be slowly spreading on the site (photograph in Appendix 5). This native species was not recorded on the site in the first eight vegetation surveys (1991 to 2000), but has been recorded in every survey since 2003. Its origin is a strip of Kangaroo Grass that has apparently been planted along the edge of the footpath adjoining National Circuit. The spread of this native species is of concern as it is not a GSM larval food (being a C4 species, Richter *et al.* 2010), and it has the potential to displace food plants.

The grasses were longer and denser than desirable for GSM habitat. The site had probably been mown once annually as recommended in the Maintenance Plan, but may not have received the second mowing required in wetter years. If the site had been mown twice, then a third mowing will be needed in such years to maintain the vegetation at a lower level.

There is evidence that some weeds have been spot-sprayed, and the southeast corner of the site had improved, becoming low diversity native-dominated rather than bare and/or exotic-dominated.

On 9 December an area of vehicle damage and compaction of the grassland was noted near the National Circuit edge of the site. A nearby office worker reported that a low loader associated with adjacent construction or maintenance work had been brought onto the site through the log barrier, carrying and unloading a tracked vehicle. Information about the time of the incursion and the contractor involved was passed on to TAMS for action.

Weeds were more common and more extensive across Blocks 3 and 7 than in previous years, including:

- Perennial grasses, including Phalaris, Paspalum, Tall Fescue, Chilean Needlegrass and Cocksfoot, particularly in the wetter southern half of the site
- Annual and perennial grasses on the bank adjacent to Sydney Avenue, an area disturbed during road widening and possibly replanted with translocated material
- Perennial grasses and Ribwort Plantain along the western boundary fence, especially where the grassland is shaded by exotic deciduous trees
- St Johns Wort and Flax-leaf Fleabane, particularly in the northern half of the site

African Lovegrass has not been recorded on the site, but is present on the National Circuit verge north of the bus stop.

3.1.3 Step-point transects

Both step-point transects showed a large reduction in the amount of bare ground on the site, and a moderate increase in the amount of litter or thatch (Appendix 2). Both changes are probably unfavourable to the emergence and breeding of GSM. The reduction in the amount of bare ground was matched by an increase in the frequency of vegetation 'hits', i.e. the vegetation was denser. Mosses and lichens (cryptogams) were also much reduced in 2011, presumably due to the increased vegetation density and reduction in bare intertussock spaces for them to occupy.

The proportion of native grasses had increased slightly in Transect 2, and decreased in Transect 1. The increase was mainly in Redleg Grass, not known to be a food plant of GSM larvae. The decrease was in the cover of Wallaby Grasses and Tall Speargrass, which are known larval food plants. Both these changes are likely to reduce the quality of GSM habitat.

Kangaroo Grass appeared in a transect for the first time in 2011. This was in Transect 1, which is closer to the strip of Kangaroo Grass beside the footpath adjoining National Circuit.

The number of native forb species recorded was similar (diversity unchanged), but their frequency (cover) was lower in Transect 2 than in previous surveys. This transect has (and maintains) higher native diversity and lower weed cover than Transect 1. The cover of exotic grasses in both transects was similar to previous years, but the cover of exotic forbs was higher. Of most concern is the appearance of St Johns Wort for the first time in both transects.

3.1.4 Quadrat assessment

As in the transect survey, bare ground and cryptogam cover was lower in 2011, and litter cover higher (photographs in Appendix 5). The cover of Tall Speargrass had increased, and the cover of Wallaby Grasses had decreased, especially the shortest Wallaby Grass *Austrodanthonia carphoides,* a species that is often associated with high GSM numbers. This may be the result of shorter grasses being shaded out by taller ones, the effect enhanced by wetter years and insufficient mowing. Kangaroo Grass was not recorded in the quadrat and has not been seen there since 2006.

The diversity of native forbs was maintained. Some that did not appear or had reduced cover in 2011 were those that rely on the availability of open ground. The Floristic Value Score for the quadrat was the highest in the three years that it has been calculated, indicating that sensitive species have been retained.

Among the exotic species there were reductions in annual grasses, probably due to decreased bare ground and competition from perennials. There were more exotic forbs, and their cover was greater in 2011. Of particular concern is the appearance of Flax-leaf Fleabane and the increase in abundance of St Johns Wort in the quadrat.

4.2 Golden Sun Moth monitoring

4.2.1 Capture and marking

Three primary sessions were completed and two were abandoned due to deteriorating weather and/or very low GSM activity in the first capture session (Table 1). There were no captures on the second day of the third session, despite two hours of capture effort (one moth was seen but not captured).

Figure 1 shows the number of new captures and recaptures for each primary and secondary session, and Table 1 shows a summary of the capture data. 94 individual GSM were captured during the three primary sessions: 50 in the first, 32 in the second, and 12 in the third. Most recaptures were in the next secondary session after first capture, but five GSM were caught in both the first and fourth sessions of a two day capture period.

No female GSM and no pupal cases were found during the surveys.

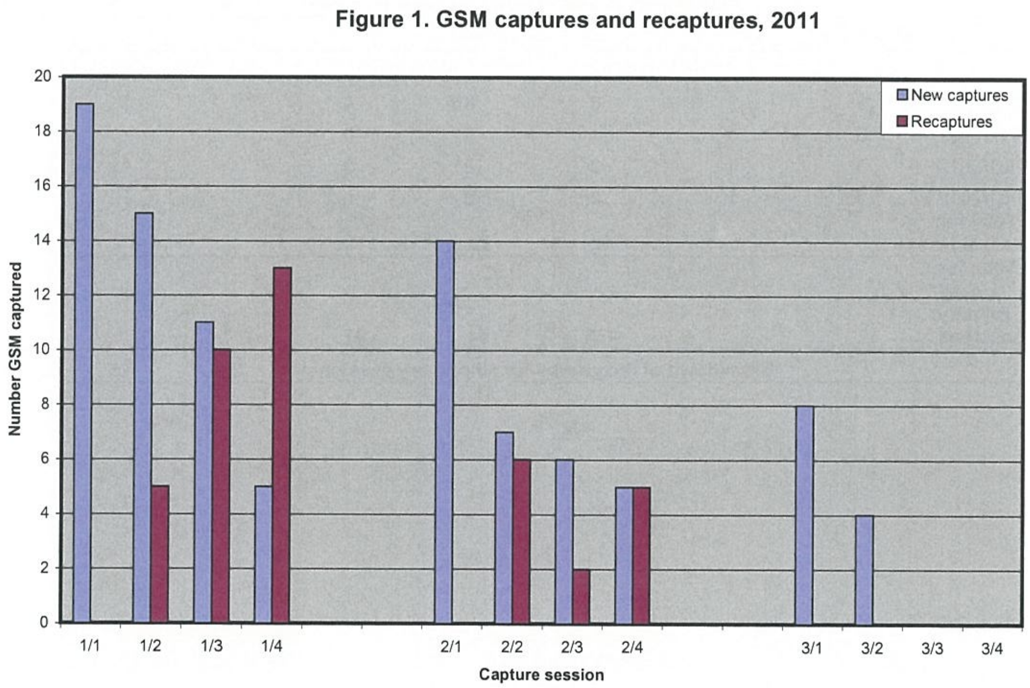


Figure 1. Golden Sun Moth captures and recaptures, December-January 2011.

Table 1. Capture data for Golden Sun Moth at York Park, 2011.

Date	Primary session	Secondary session	Total captures	New captures	Recaptures	Recaps: Sessions since first capture 1	2	3
9/12/2011	1	1	19	19				
9/12/2011	1	2	20	15	5			
10/12/2011	1	3	21	11	10			
10/12/2011	1	4	18	5	13			
Total for session			**78**	**50**	**28**			
		Breakdown of recaptures for primary session:				**14**	**12**	**2**
16/12/2011	abandoned	1	1					
23/12/2011	2	1	14	14				
23/12/2011	2	2	13	7	6			
24/12/2011	2	3	8	6	2			
24/12/2011	2	4	10	5	5			
Total for session			**45**	**32**	**13**			
		Breakdown of recaptures for primary session:				**9**	**3**	**3**
30/12/2011	abandoned	1	1					
31/12/2011	3	2	8	8	0			
31/12/2011	3	3	4	4	0			
1/01/2012	3	4	0	0	0			
1/01/2012	3	5	0	0	0			
Total for session			**12**	**12**	**0**	-	-	-
Total for all primary sessions			**135**	**94**	**41**			
		Breakdown of recaptures for all primary sessions:				**23**	**15**	**5**

4.2.2 Analysis

In the first two primary sessions moths were recaptured in all three subsequent secondary sessions, allowing estimation of the total population size during the primary sessions (see Appendix 4 for details). The data was sent to Dr Anett Richter for analysis using the software MARK. The package includes the estimation of total population size, and provides estimates of daily survival rates and recapture probabilities. The population size during the first primary session was estimated at 66 individuals, for the second session 49 individuals, and the estimate of animals present during the third session was just the number of individuals captured (i.e. 12, 'minimum number alive'), due to lack of recaptures (Table 2 and Appendix 4).

Table 2. Primary session Golden Sun Moth population estimates, York Park, 2011.

Primary session	Dates	Position in flying season	Estimated population size during session	95% confidence interval
1	9-10 December	mid	66	57 - 85
2	23-24 December	mid to late	49	39 - 75
3	31 Dec – 1 Jan	late	12*	-

*Minimum Number Alive, population estimate not possible due to lack of recaptures

Dr Richter also used program JOLLY to analyse the data. This program estimates the size of a population based on the assumption that the population is "open" (birth, death, immigration and emigration occur). She found that our data was not suitable for this analysis, which takes the survival and recapture rate between sampling sessions as the basis for the estimation. The analysis was limited due to lack of recaptures between primary sessions, and stopped due to insufficient data.

This means that the 2011 data cannot be used to produce an estimate of the total population of adults emerging during the season. However, it can be used as an indication of relative daily numbers for comparison with future years, and can be compared with previous data in a number of ways.

4.2.3 Comparison with previous surveys

Number of flying days in season

It is likely that fewer GSM emerged at York Park in 2011 compared to previous years due to the relatively low number of days of suitable flying weather. The approximate length of the flying period at York Park for each year was determined from previous reports and 2011 observations. The number of days each season when GSM were flying at York Park was then taken from previous reports or estimated from GSM observations plus weather data. Days in 2011 with more than 1 mm of rain and/or a maximum temperature below 21°C were excluded. This showed that GSM were able to be active on markedly fewer days in 2011 than in previous years (Table 3).

Table 3. Golden Sun Moth activity at York Park

Year	Approximate length of flying period at York Park	Number of days with GSM activity At York Park
1992	59	49
1993	48	36
1994	45	40
2006	45 (minimum)	35 (estimated)
2011	45	21 (estimated)

The weather in spring 2011 was both cooler and wetter than average. The mean temperature at 3 p.m. during the 2006 York Park survey period was 28.8 C, while for the 2011 survey period it was only 22.7 C, despite the 2011 survey taking place later in the summer (Figure 3).

In November, 113 mm of rain fell (long term average 64 mm), and there were 10 days with more than 1 mm of rain. In December, the highest maximum temperature was 28.8°C and only seven days had a maximum over 25°C. On several of the days of apparently unsuitable weather, searches at York Park or in other known habitat confirmed that there was no GSM activity. The Permit to Take only covered 33 days of the 2011 York Park flying season, of which 15 days were unsuitable for GSM activity. In contrast, only one day during the 26 day trapping period at York Park in 2006 had no GSM activity, as did four days out of 45 in 1994.

Daily first captures

In previous surveys capturing was undertaken for one hour daily, while in 2011 there were two such capturing sessions on each of a smaller number of days. To allow comparison with the 2006 data, the daily first captures for the first hour of each 2011 survey day were plotted with the daily first captures for each day in the 2006 survey (Figure 2). Due to the different seasonal conditions in the two years, and the late application for the Permit to Take in 2011, the survey periods only overlap for a few days. This is probably not important, as moths were flying well on those days in both years, and the length and timing of the season varies year to year. In 2006 the season ended in mid-December, but in 1992, 1993 and 1994 the peak of the season was from early to late December.

It can be seen that the numbers of first captures of GSM per hour in both years using the same survey effort fell within the same range. In 2006 it was found that above a certain density of GSM, capturing and marking 20 moths in one hour was near the maximum possible for a team of two people, given that one person became fully occupied extracting, marking and caging moths. In the three surveys between 1992 and 1994, there were only two occasions where more than 25 moths were captured in one hour.

Figure 2. Daily first captures of GSM at York Park, 2006 and 2011

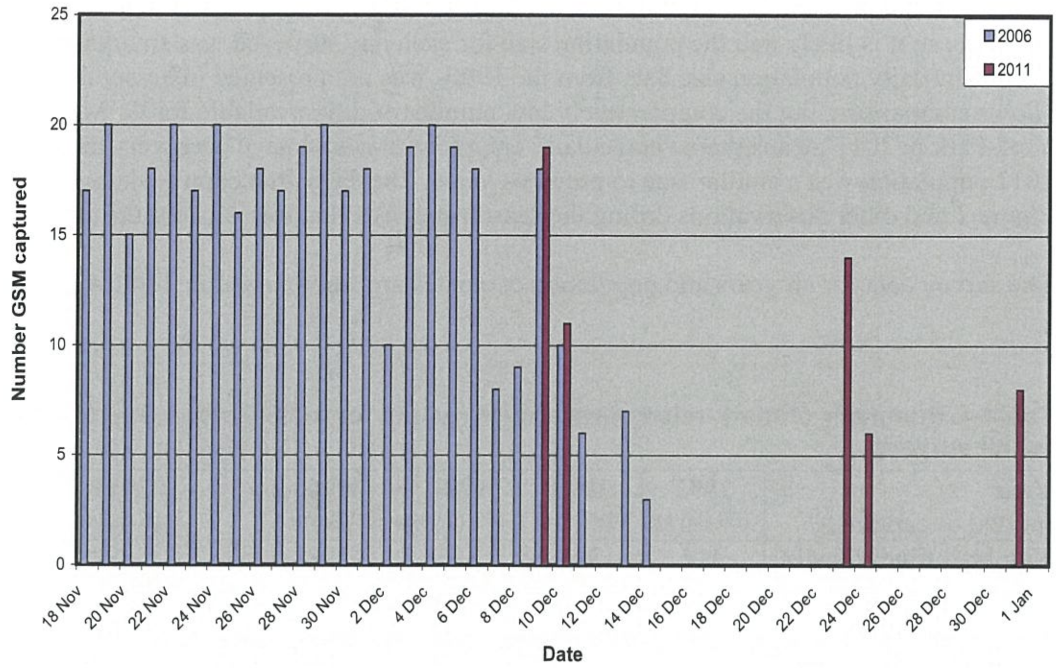
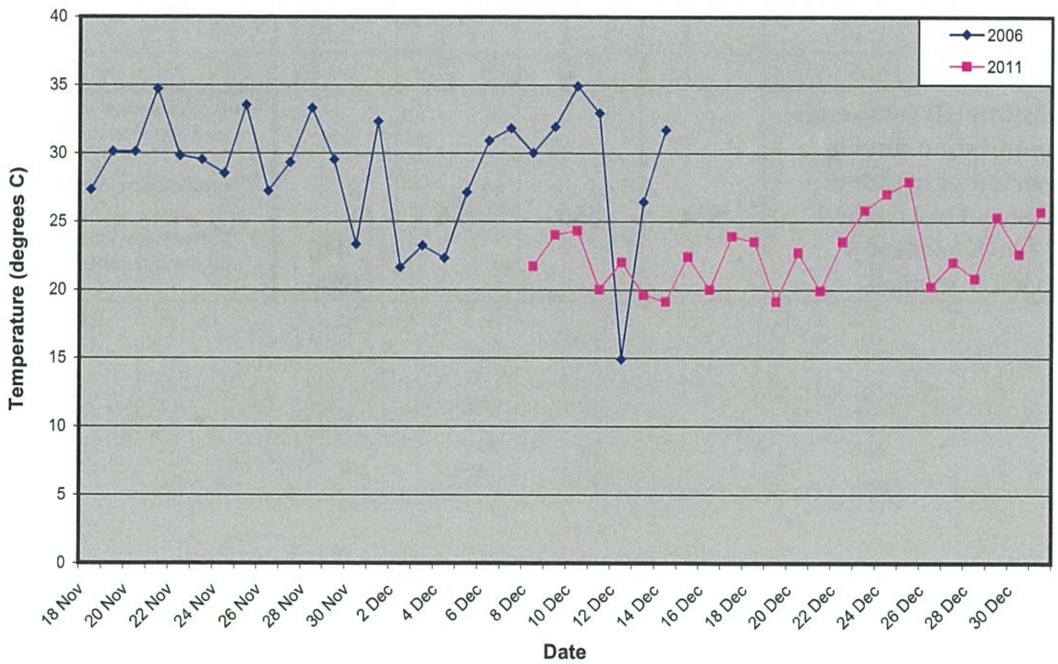


Figure 3. Temperature at 3 p.m. during GSM surveys in 2006 and 2011



Estimated daily population size

The estimated daily population sizes from the 2006 survey were between 50 and 65 GSM during the peak of the season. This is similar to the numbers estimated for the first two primary sessions in 2011 (66 and 49 individuals), but these sessions cover two days rather than one, so it is likely that the population size for each day surveyed was smaller in 2011. The daily population size data from the 1990s was not presented in a way that allows comparison, but the comparatively low number of days available for GSM to fly at York Park in 2011 means that average daily emergences would have been very high if the 2011 population was a similar size to previous years. The daily first capture data in Figure 2 and other observations during the season suggests that this was not the case.

The survey data for all years and population estimates are summarised in Table 4.

Table 4. Summary of mark-release-recapture results for male Golden Sun Moths for all surveys.

Year (period of captures)	**1992** (69 days)	**1993** (48 days)	**1994** (45 days)	**2006** (27 days)	**2011** (6 days)
Number of individuals captured	317	321	375	398	94
Total captures	354	389	419	423	35
Recaptures after 1 day	25	54	30	21	After 1 session: 23 After 2 sessions: 15
2 days	8	8	10	4	After 3 sessions: 5
3	2	2	2	0	
4	1	1	1	0	
5	1	0	0	0	
Estimated total male population during period of captures: Fisher-Ford method MARK method JOLLY method	 **524**	 **456**	 **736**	 **440** **1230**	**Daily population estimate:** 1st primary session: **66** (57-85) 2nd primary session: **49** (39-75) 3rd primary session: **12*** (*minimum number alive)

5. Discussion and Recommendations

5.1 Vegetation condition

5.1.1 Weeds

A number of species discussed here are either Weeds of National Significance (WONS) and/or declared pest plants in the ACT (see Table 5 and Maintenance Plan). The management aim for these species should therefore be eradication. A request should be made to the appropriate managing body for the patch of African Lovegrass on the National Circuit verge to be controlled, as it poses an invasion threat to the site.

Table 5.Significant weed species

Weed species	Common name	WONS	ACT Pest Plant	Present 2011
Echium plantagineum	Paterson's Curse		yes	no
Eragrostis curvula	African Lovegrass		yes	road verge
	Thistles (Spear, Scotch, Saffron etc)		yes	no
Hypericum perforatum	St John's Wort		yes	yes
Nassella neesiana	Chilean Needlegrass	yes	yes	yes
Nassella trichotoma	Serrated Tussock	yes	yes	no

Control of some weed species (Paterson's Curse, Serrated Tussock) has been successful recently, but other species have increased since 2007. Some perennial grasses have increased in both density and extent, mainly on and near the bank at the southern end and along the western boundary where the grassland is shaded by exotic trees growing outside the fence. These trees are probably self-sown, and removing them would protect the grassland from shading and leaf fall. Where patches of perennial grasses and Ribwort Plantain have formed dense patches on the site, spraying followed by rehabilitation with native species is desirable. Any replanting on this site should use Wallaby Grasses, to enhance GSM habitat. Several species occur naturally on the site, some are suited to wetter areas and some do better in well-drained areas.

St Johns Wort and Flax-leaf Fleabane were both common across the site in 2011. Fleabane had not been recorded since 1996, and has been a prominent weed in the ACT in the last two years. St Johns Wort first appeared at York Park in 2003 and has been increasing since. The spread of both may be slowed by more frequent mowing, as both mostly form seed when the plant is 30 cm or more tall. The Fleabane may decline without other management action, as it is an annual species and its recent spread may be due to the extensive bare ground that was available for colonization at the end of the drought. The higher ground cover now present may suppress seedling establishment.

St Johns Wort is a perennial species, and very invasive. It was previously rare at York Park, and the Maintenance Plan recommended hand-pulling after rain. Given its spread in the last two wetter years, plants should be spot-sprayed, taking care to localize the herbicide to the target plants.

The (apparently planted) Kangaroo Grass strip along the edge of the National Circuit path performs a useful function on this small site, effectively suppressing the incursion of weeds from the verge, which may otherwise thrive in the increased moisture that runs off the path. However, Kangaroo Grass is not thought to be a GSM larval food, and its spread should be monitored and contained within a 2 metre strip, as it can also suppress other native species, to the detriment of NTG and GSM habitat quality. It was not recorded on the site prior to 2003, though may have been present before 1991 when botanical surveys of the site began.

A patch of River Tussock was planted in a damp area at the foot of the bank in the south-west corner of the site some years ago. This is a native species, but not recorded as occurring naturally on the site in surveys going back to 1991. This species is also quite effective at suppressing exotic perennial grasses and has not expanded from its original location, so should be retained.

5.1.2 Biomass control

The mowing schedule may have followed the recommendations in the Maintenance Plan, but appears to have been inadequate for the two recent wet years (see photographs, Appendix 5). If the leaf height of the grass is above 15 cm near the beginning of the GSM flight season, it should be cut back to about 10 cm. Even if GSM have already begun to fly, the benefit gained from more open habitat is likely to offset the disturbance to emergence, mating and egg-laying of GSM during one or two days around the mowing.

The cover of the shorter Wallaby Grasses was lower in 2011, and this may also be due to the shorter grasses being shaded out by taller species such as Tall Speargrass.

The vegetation in the southern area including the weedy bank adjacent to Sydney Avenue becomes very long and dense at times, and slashed material should be raked and removed after mowing. Removing this material will take nutrients off the site and favour native species over exotics, while leaving layers of cut material to mulch down favours weed establishment.

5.2 Golden Sun Moth population

The numbers of flying adults in a season is influenced by conditions around the time of emergence, but also by the survival of eggs, larvae and pupae over the previous two years, which is presumably affected by rainfall, temperature and habitat condition.

This consultant (and others using York Park as a reference site) observed GSM flying at York Park on 17 days during the 2011 season. The highest number reported was nine GSM flying in a five-minute period. This is in the Low category (2 or less per minute) for a standing fixed count in the semi-quantitative assessment system proposed by Hogg (2009). Given the low number of suitable flying days in 2011, high numbers of GSM could have been expected to emerge on the few hot dry days, but this was not observed.

This result is in accordance with GSM surveys for the rest of the northern ACT in 2011, where numbers from transect counts of two large sites were less than 10% of the counts recorded in 2009 (pers. obs.). Other consultants reported lower than usual numbers at other known sites. The daily capture rate and population estimates suggest that the reduction in numbers at York Park was not as great as occurred on a number of other sites. However, the small size and large edge-to-area ratio of this site make the GSM population vulnerable to habitat deterioration, and optimal habitat management should be maintained at the site. Recommendations relating to weed and biomass control are made in Section 5.1 above.

The Robust Design method did not give ideal results in the very unusual 2011 spring. The rarity of two consecutive days of good flying weather prevented the completion of the planned number of primary sessions, but the comparisons that were possible with previous years suggested that the York Park population was lower in 2011. This type of survey is nevertheless appropriate for this species with unusually short-lived adults, as it uses four capture-mark sessions within two days to maximise recaptures. This gives more accurate population estimates for the period of the primary sessions (Table 2), and it is recommended that future surveys use the same method, with up to five primary sessions during the season. The sessions should span the whole season and represent early, mid and late season GSM activity. The start and finish of the season at York Park should be determined, and the number of days on which GSM are active. These data taken together will provide a basis for comparing the population size from year to year, and the data collection will be less intrusive and potentially damaging to the GSM and their habitat than daily mark-release-recapture studies which cover the whole flying season.

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GOLDEN SUN MOTH MONITORING 2015

York Park

SMEC Australia Pty Ltd

Prepared for: 22 Barton Pty Ltd

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

Introduction

SMEC Australia Pty Ltd prepared this monitoring report on behalf of the ACT Government Land Development Agency to meet the 2016 annual reporting requirements of the *Potential shading impacts on York Park golden sun monitoring plan* (RJPL 2014a, the monitoring plan)., primarily the year 3 golden sun moth (*Synemon plana,* GSM) flying moth survey, pupa case search and vegetation condition assessment conducted in 2015 in accordance with the monitoring plan.

Results

Data is provided in summarised form suitable for incorporation into future trend analysis. All survey data is presented Appendices A and C. Meteorological data obtained for Canberra Airport from the Bureau of Meteorology is summarised in Appendices C and D.

The key results are:

- Flying GSM were recorded in moderate numbers at the beginning of the flying season (i.e. mid-November) but decreased quickly to low number by early December. Flying moth abundance was roughly consistent with previous surveys;
- A total of six pupae cases were found, consistent with the very low detection in previous survey surveys. This detection rate is too low to enable meaningful BACI analysis of pupae cases;
- Vegetation condition was generally lower in comparison to previous surveys, particularly the 2014 survey, however this was more pronounced within the control zone and is likely to be attributable to survey timing and seasonal conditions;
- Data could be downloaded from only two of the four soil temperature data loggers due to a manufacturer's software upgrade error;
- It is not possible to make any judgements relating to long-term trends in GSM abundance or vegetation condition based on the three years of monitoring data collected to date.

This report fulfils the reporting requirements for GSM monitoring at the York Park for year 3 as specified in the monitoring plan (RJPL 2014a).

Recommendations

It is recommended that data loggers be replaced with a more reliable model prior to winter 2016. In addition, discussions with should DoE be undertaken to review the following recommended amendments to the GSM monitoring plan:

- the pupae case surveys and associated analyses should be removed from the monitoring plan as detection of pupae cases is insufficient for meaningful analysis;
- the importance of monitoring soil temperatures should be reviewed after one additional full season of monitoring, and, if there is no substantial difference in soil temperatures within shaded and unshaded areas after this period, potentially removed from the monitoring plan.

1. INTRODUCTION

SMEC Australia Pty Ltd prepared this monitoring report on behalf of Section 22 Barton Pty Ltd to meet the 2015 annual reporting requirements of the *Potential shading impacts on York Park golden sun monitoring plan* (RJPL 2014a, the monitoring plan). The monitoring plan was developed to meet Commonwealth *Environment Protection Biodiversity Conservation 1999 Act* (EPBC Act) approval decision (*EPBC 2012/6606*) conditions for development of a hotel and carpark at Block 14 Section 22 Barton (14/22 Barton). The report contains detailed descriptions of the site, proposed actions and monitoring procedures (RJPL 2014a).

This report presents the Year 3 baseline monitoring surveys undertaken in spring and summer 2015 for flying golden sun moth (*Synemon plana*, GSM), GSM pupae cases and vegetation condition at York Park.

Year 1 and Year 2 baseline surveys are presented in the York Park Golden Sun Moth Monitoring 2013 survey report (RJPL 2014b) and 2014 survey report (RJPL 2015) and, where relevant, have been referenced for comparison. Limited assessment and analysis of the monitoring data is possible after the 3rd year of data collection during the 2015 GSM flying season, and BACI analysis is not to be commenced until after the 5th year of data collection (RJPL 2014a).

2. METHODS

2.1 Regional GSM Information

GSM information, including sightings, general locations and activity levels around the ACT region were shared by researchers and consultants via email on a weekly basis during the GSM flying season. As this communication was intermittent, no summary of GSM activity recorded throughout the region could be produced.

2.2 Flying Moth Surveys

As specified in the monitoring plan (RJPL 2014a), flying GSM surveys were conducted in a manner consistent with the ACT Government (2010a) GSM survey guidelines and with the annual monitoring approach presented in Umwelt (*in prep*), as follows:

- Flying GSMs would be counted along two 100 m transects along the long axis of York Park (Figure 1) and recorded as number of GSM per 100 m transect.
- The transect survey would be undertaken three times approximately half an hour apart.
- To compare baseline GSM activity levels with post-shading GSM activity levels, two sets of rotational point counts, involving 10 repeated, 30 second rotational counts, would be conducted at one site in the centre of the York Park GSM site between the transect surveys (Figure 1). All GSM seen in a radius of 25 m are to be recorded. Any individuals that re-crossed the observer's visual path were double counted. Averages were calculated from the ten rotations at each point to provide number of GSM per 30 second rotation. Data recorded using this approach is comparable with data collected by Umwelt (Australia) Pty Ltd for the year 1 and year 2 surveys (RJPL 2014b, RJPL 2015).
- To compare activity levels in the northern and southern ends of the York Park GSM site, two sets of rotational point counts, involving 10 repeated, 30 second rotational counts, would be conducted at two sites approximately one third and two thirds of the way along the centre line of York Park GSM site between the transect surveys (Figure 1), i.e. approximately 25 m from each end. All GSM seen in a radius of 25 m are to be recorded. Any individuals that re-cross the observer's visual path would be double counted. Averages were calculated from the ten rotations at each point to provide a number of GSM per 30 second rotation.

The start of the GSM flying season was confirmed using known reference sites in the ACT, including York Park, and consultation with the ACT GSM monitoring group. In practice, suitable daily weather conditions determine repeat survey timings and shorter survey return times of no less than 3 days may be applied.

Other on-site weather data was recorded during all field surveys of flying GSM to assist with interpreting the GSM survey results on a year to year basis. The following data was recorded during flying moth surveys:

- wind speed and direction
- air temperature
- cloud cover.

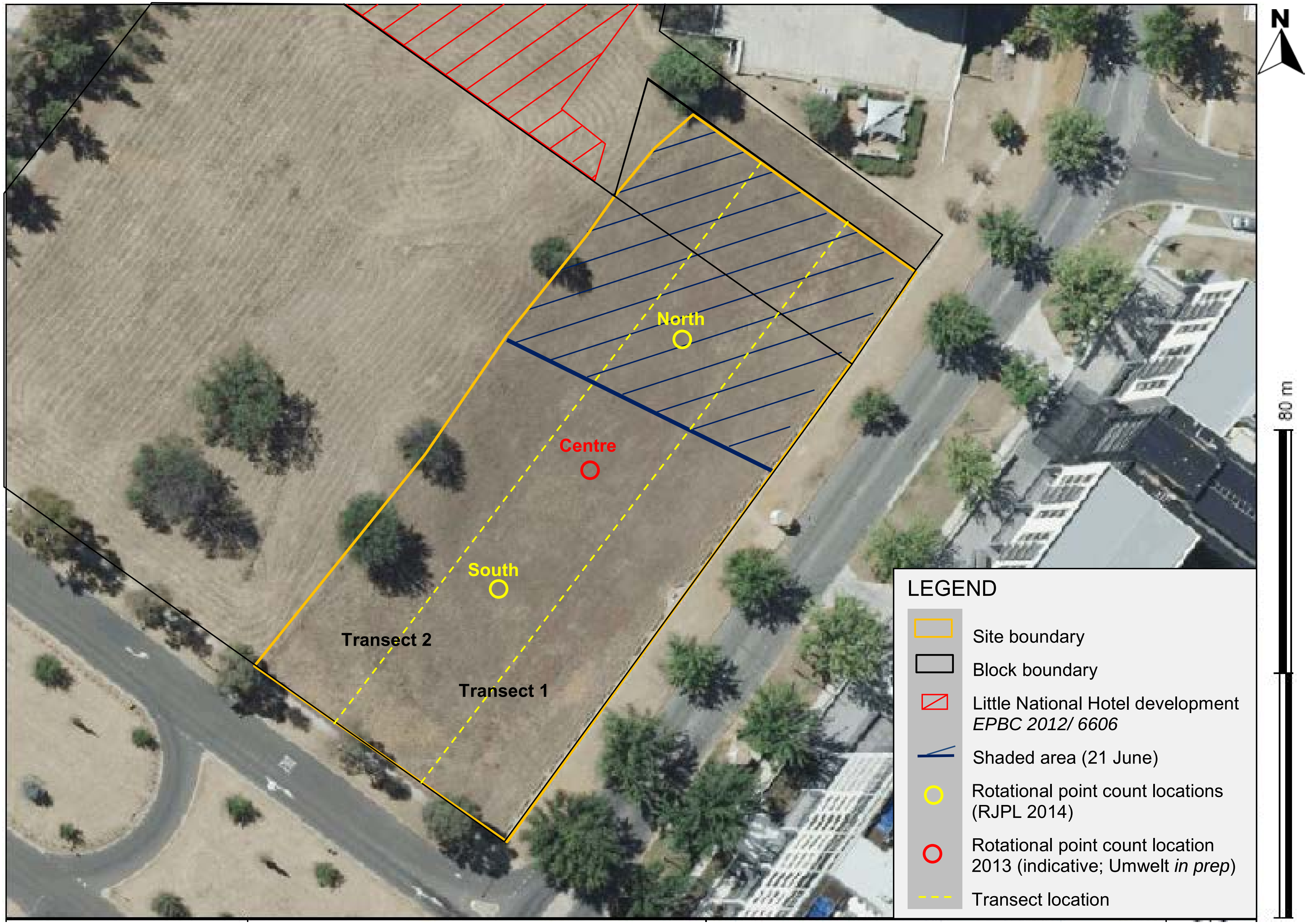

Figure 1. York Park GSM site flying moth survey details 2015.

2.3 Survey Area and Quadrat Placement

The survey area defined in the monitoring plan (RJPL 2014a) incorporates the York Park GSM site, and excludes the area now developed for road access to 14/22 Barton and areas of exotic perennial grasses and native *Poa* and *Themeda* plantings (Rowell 2012). As specified in the monitoring plan, the site is stratified into the following four zones for the pupae case surveys and vegetation assessments:

- Zone 1a: shaded by the proposed development at 14/22 Barton (impact)
- Zone 1b: shaded by the proposed development at 14/22 Barton and potentially shaded by the proposed development at Part 3/22 Barton (impact)
- Zone 2a: unshaded by the proposed development at 14/22 Barton and unshaded by the proposed development at Part 3/22 Barton (control)
- Zone 2b: unshaded by the proposed development at 14/22 Barton but potentially shaded by the proposed development at Part 3/22 Barton (control).

Twenty-four, 1 m^2 quadrats were established across the site at the beginning of the year 1 baseline survey season (RJPL 2014b). Each of these locations was approximately relocated using GPS locations and the map provided in the monitoring plan (RJPL 2014a). Plots were marked using wire pegs and plastic tags installed flush with the ground to permit relocation of the quadrats for repeat sampling during the season. All plot markers were removed at the end of the season. Figure 2 shows the York Park and GSM transect and plot locations and quadrat placement.

2.4 Pupae Case Monitoring

Pupae case surveys were conducted as specified in the monitoring plan (RJPL 2014a). Pupae cases were counted in each of the 24 quadrats approximately every two weeks over a six week period (i.e. 3 times) during the GSM flying period from early-to-mid November until late December. All cases detected were removed for identification (e.g. using microscopy). This would ensure that individual pupae cases were counted in one survey only.

2.5 Vegetation Monitoring

Data recorded for each quadrat included:

- all species present
- the dominant species (single or multiple)
- cover / abundance (%) using the Braun-Blanquet cover / abundance classes outlined in ACT Government (2010b).

Floristic value scores were calculated from abundance data based on Rehwinkel (2007) consistent with ACT Government (2010b).

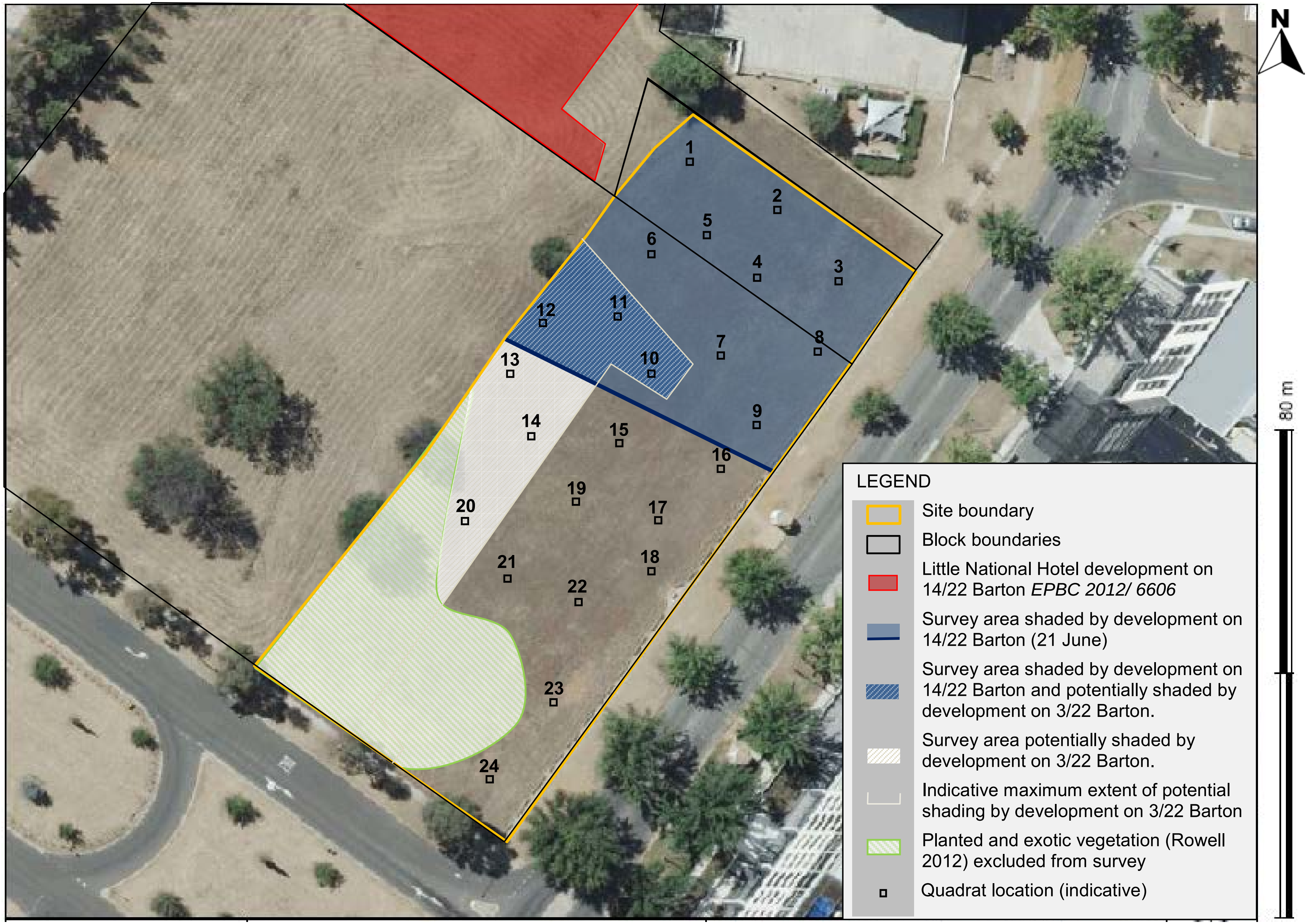

Figure 2. York Park pupae case and vegetation quadrat locations.

2.6 Soil Temperature Monitoring

On-site soil temperature monitoring in shaded and un-shaded areas commenced on 21 October 2014. One temperature logger were recovered on the 18 December 2015 and the other three temperature loggers were recovered on 1 February 2016.

2.7 Meteorological Data

Meteorological data from Canberra Airport was obtained for the period 2013-2015 to assist in the interpretation of potential shading impacts.

3. RESULTS

3.1 Regional GSM Information

GSM were first observed flying in the ACT on 18 November 2015 and were confirmed to be flying in moderate numbers at multiple sites in the ACT in mid to late November 2015 (A. Rowell, pers. comm.). The flying season was confirmed to have started throughout the region by the end of the third week of November 2015, which was approximately two weeks later than flying was confirmed in 2014. This delay is believed to be due to regular rain in early November. Peak activity in the ACT region is thought to have occurred around late November, with GSM activity tapering off into early December and finishing by mid-December (A. Rowell, pers. comm.).

3.2 Flying Moth Surveys

Flying GSM were surveyed according to the method specified in the monitoring plan (RJPL 2014a) on three occasions approximately two weeks apart during the GSM flying period. Table 3-1 presents the dates and weather conditions of each survey. All surveys were conducted on suitable days. Other consultants and researchers also conducted surveys at various sites in the Canberra region and detected flying GSM (CPR, unpublished data).

Table 3-1. Site conditions during flying moth surveys.

Date	Max Temperature (ºC)	Rainfall (mm)	Wind speed and direction	Cloud cover
19/11/2015	34.5	0	Calm	Fine
25/11/2015	25.0	0	2.3 km/h NNW	Fine
1/12/2015	25.0	0	Gentle breeze (4 km/h E)	Fine, no cloud

Appendix A presents the complete dataset for the flying moth surveys. Table 3-2 and

Table 3-3 present aggregated survey results for transect surveys and rotational point counts respectively.

Table 3-2. Summary of flying GSM numbers - Transect surveys.

Transect	Transect location	Average (1dp)
Transect 1	East	10.2
Transect 2	West	8.6
Combined		9.4

Table 3-3. Summary of flying GSM numbers - Point count surveys.

Time	Location	Average (1dp)	Range
N/A	North	1.4	1 - 5
12:00	Centre	1.9	0 - 8
12:15	Centre	3.0	1 - 12
Centre Combined	Centre	2.4	1 - 12
N/A	South	2.0	0 - 7

3.3 Pupae Case Surveys

Pupa case surveys were conducted according to the method specified in the monitoring plan (RJPL 2014a) on three occasions. Surveys were undertaken on 25 November 2015, 1 December 2015 and 15 December 2015.

Appendix B presents the complete pupa case survey dataset. Table 3-4 presents a summary of the pupa case survey results for the control and impact zones. The location of pupae cases recorded in York Park is shown in Figure 3. Low pupa case numbers were recorded, i.e. three pupae cases were recorded in Zone 1a, two pupae cases were recorded in Zone 2a and one pupa case was recorded in Zone 1b. No pupae cases were recorded in Zone 2b.

Table 3-4. Summary of the pupae case surveys within control and impact sites.

	Pupae cases	
Zone	**Average (1dp)**	**Maximum number**
Zone 1a	0.3	2
Zone 1b	0.3	1
Zone 1 (impact)	**0.3**	**2**
Zone 2a	0.2	1
Zone 2b	0.0	0
Zone 2 (control)	**0.1**	**1**

3.4 Vegetation Surveys

Dominant species, percentage cover and complete species lists, including Braun-Blanquet abundance scores, were collected for each quadrat. All data is presented in Appendix C. Species recorded are shown relative to the York Park GSM site cumulative species list of Rowell (2012) and RJPL (2014a), with a summary of the floristic value calculations for each quadrat. Table 3-5 presents a summary of the key vegetation quality indicators for the control and impact zones. The location of quadrats where a floristic score of 4 or greater was recorded are shown in Figure 3.

Table 3-5. Vegetation survey summary for the control and impact sites.

Zone	Floristic score		Native species	Exotic species	Cover (%)
	Average (1dp)	**Maximum**	**Average Number (1dp)**		**Average**
Zone 1a	1.3	4	5.0	5.3	72
Zone 1b	1.6	4	5.6	5.0	83
Zone 1 (impact)	**1.4**	**4**	**5.2**	**5.2**	**75**
Zone 2a	0.3	2	4.3	5.7	79
Zone 2b	0.2	1	3.4	5.7	65
Zone 2 (control)	**0.3**	**2**	**3.7**	**5.7**	**77**

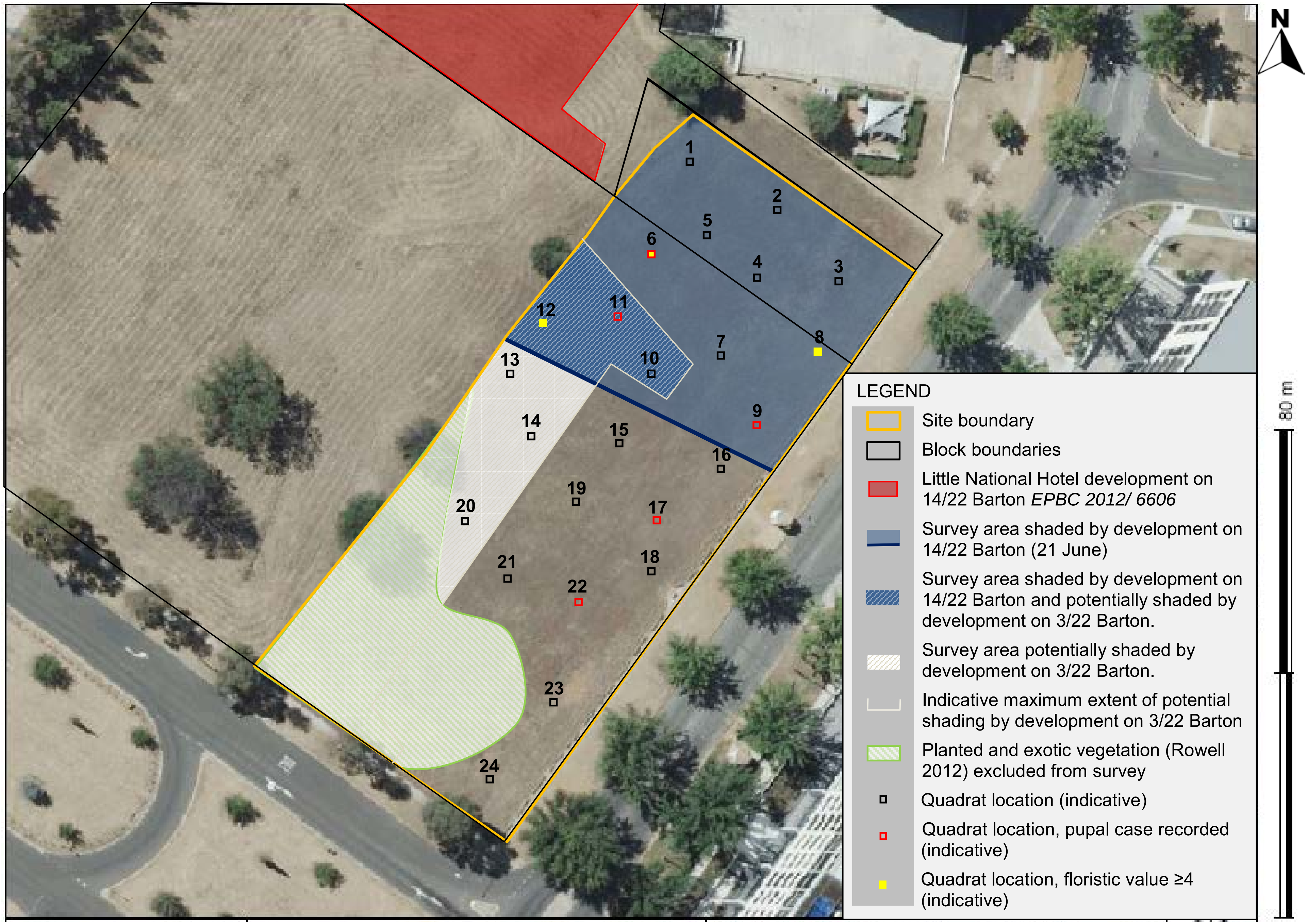

Figure 3. York Park pupae case and vegetation survey summary.

3.5 Soil Temperature Monitoring

One soil temperature logger (Zone 1b) was recovered on 18t December 2015. The other three soil temperature loggers were recovered on 2 February 2016.

Data could not be downloaded from two of the data loggers recovered (i.e. Zone 1a and 2a). Discussion from the wholesaler identified that since the last download, an update in the software has caused some data loggers to be locked with a password and retrieving data from these temperature loggers is impossible. Due to the software changes, subsoil temperature data for further analysis is unavailable for Zone 1a and Zone 2a.

The maximum daily and minimum daily temperatures recorded by the loggers are presented in Appendix D. Table 3-6 presents the mean monthly temperature, mean maximum daily temperature and mean minimum daily temperature by month. Complete soil temperature data files are provided with this report.

Table 3-6. Soil temperature data recorded at York Park.

	Zone 1b			Zone 2b		
Month	**Mean (ºC)**	**Mean Daily Max (ºC)**	**Mean Daily Min (ºC)**	**Mean (ºC)**	**Mean Daily Max (ºC)**	**Mean Daily Min (ºC)**
October 2014 (16 days)	16.6	20.0	13.7	17.5	20.8	14.8
November 2014	22.7	21.4	14.7	24.2	22.4	15.4
December 2014	24.0	27.3	18.9	24.8	29.6	20.3
January 2015	24.8	28.6	21.8	25.2	28.9	22.3
February 2015	24.3	27.9	21.5	24.6	28.8	21.9
March 2015	22.3	26.4	19.2	22.6	26.6	19.5
April 2015	15.9	18.0	14.2	16.0	18.2	14.1
May 2015	11.5	13.5	9.8	11.6	13.7	9.7
June 2015	7.7	9.4	6.2	8.1	9.9	6.6
July 2015	6.7	8.4	5.4	6.9	8.6	5.5
August 2015	8.7	11.0	6.9	8.9	11.1	7.1
September 2015	19.3	15.8	9.9	20.0	16.1	10.2
October 2015	19.3	23.2	16.2	20.0	24.2	16.9
November 2015	21.4	27.6	18.9	22.4	29.6	20.3
December 2015	25.5	27.7	20.2	27.2	28.6	21.0

Figure 4 shows a plot of mean monthly soil temperatures recorded at York Park in 2014 and 2015 in each of the zones for which data is available. The plot indicates that differences in winter soil temperatures between the control and impact zones are negligible, particularly during winter, with the difference in monthly mean temperature between the control and impact sites varying between 0.1˚C and 0.4˚C between May and August, within the ±0.5˚C recording error of the temperature data loggers. The divergence in summer temperatures between the control and impact zones occurred in both seasons, but is not caused by shading impacts, as the site is unshaded during this period. Winter temperatures in Zones 1a and 2b were lower in 2015 relative to 2014. The consistency in this shift between both the impact (1b) and control (2b) zones indicates that this change is not due to shading impacts, but is likely to be due to yearly differences in seasonal conditions. This interpretation is consistent with the meteorological data presented in Section 3.6.

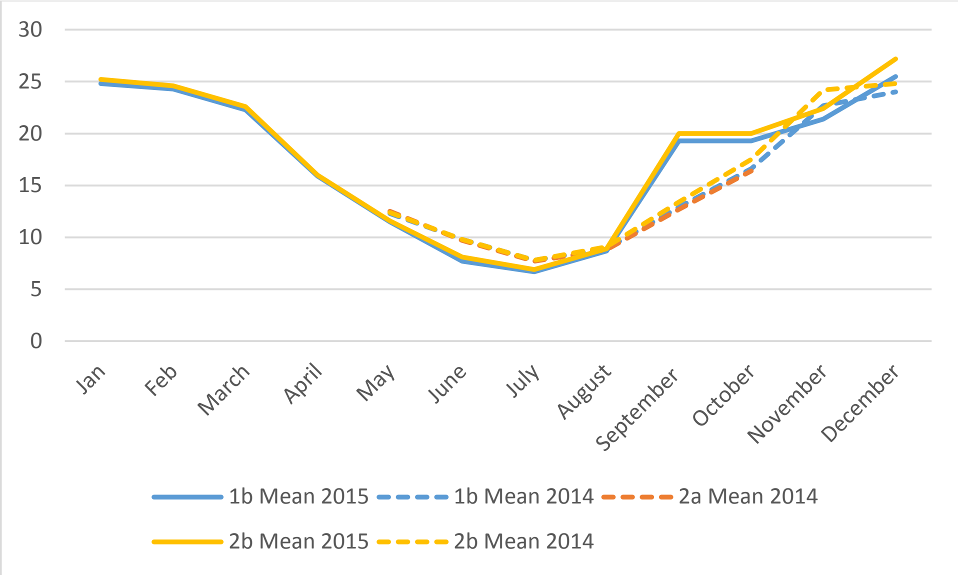

Figure 4. Comparison of mean monthly soil temperatures between zones and between years.

3.6 Meteorological Data

Figure 5 presents monthly rainfall and average daily maximum and minimum air temperatures recorded at Canberra Airport from 2013 to 2015. Figure 6 shows the monthly average daily maximum and minimum soil temperatures, recorded at 10 cm depth from 2013 to 2015 at the Canberra Airport, although some data is missing for 2013, limiting comparison between years. The soil temperature data (Figure 6) confirms the cooler winter soil temperatures recorded in 2015 relative to 2014 at York Park (Figure 4).

Figure 7 shows, in more detail, daily maximum soil temperature and daily precipitation during the GSM flying season (i.e. October to December). The Bureau of Meteorology was unable to provide soil temperature data for November and December 2013, restricting comparison between 2013 and 2014.

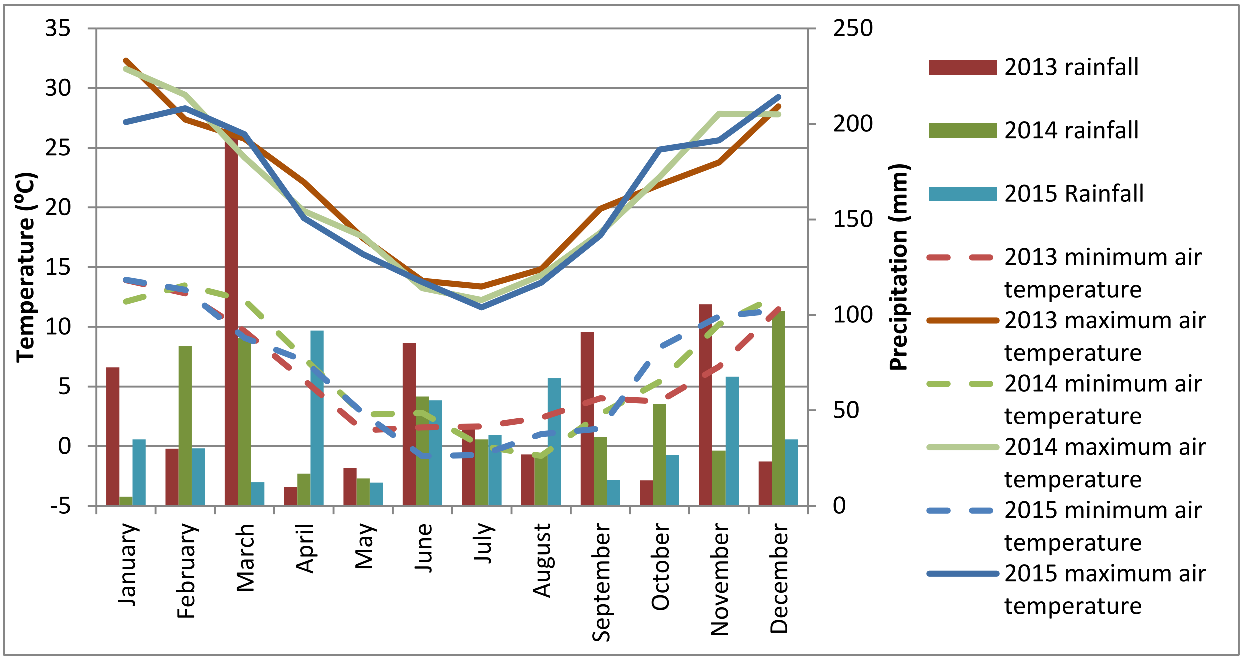

Figure 5. Monthly rainfall and average daily maximum and minimum air temperature.

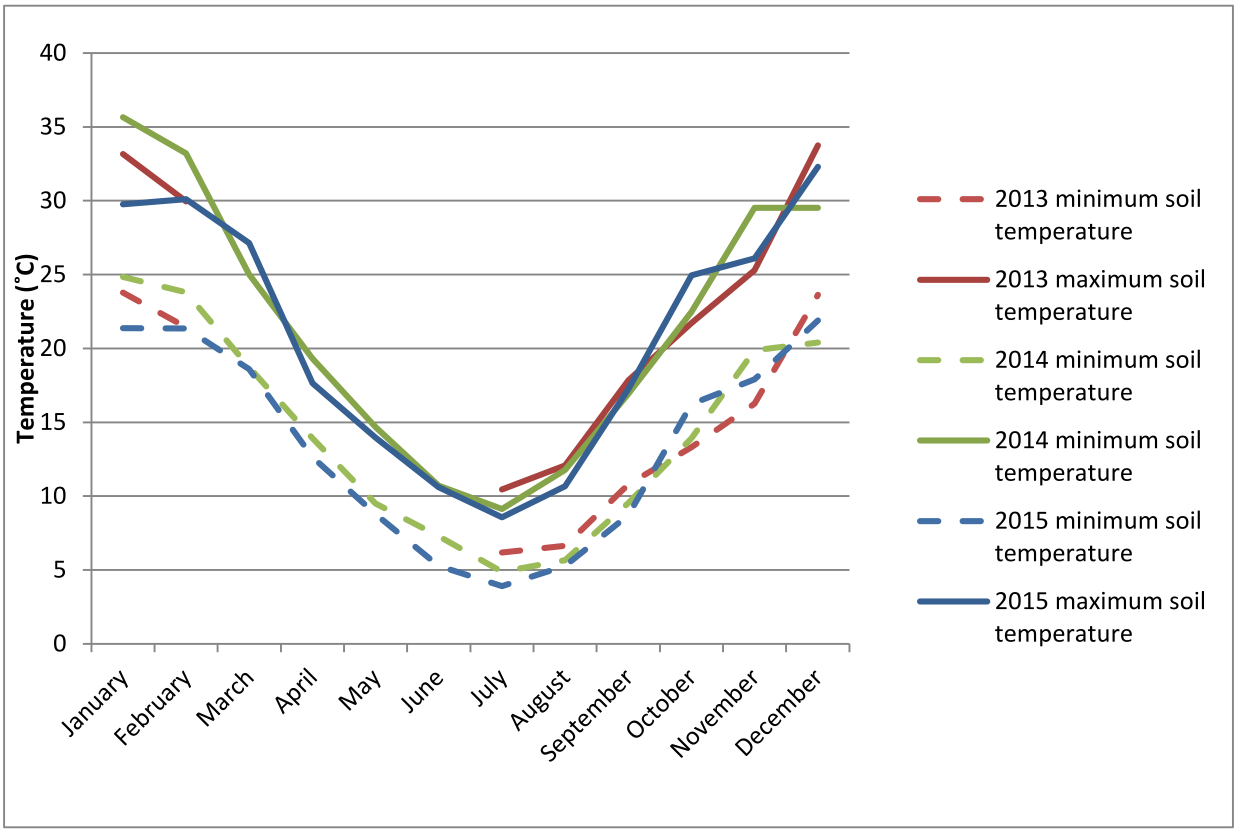

Figure 6. Monthly average daily maximum and minimum soil temperature (10 cm depth) at Canberra Airport.

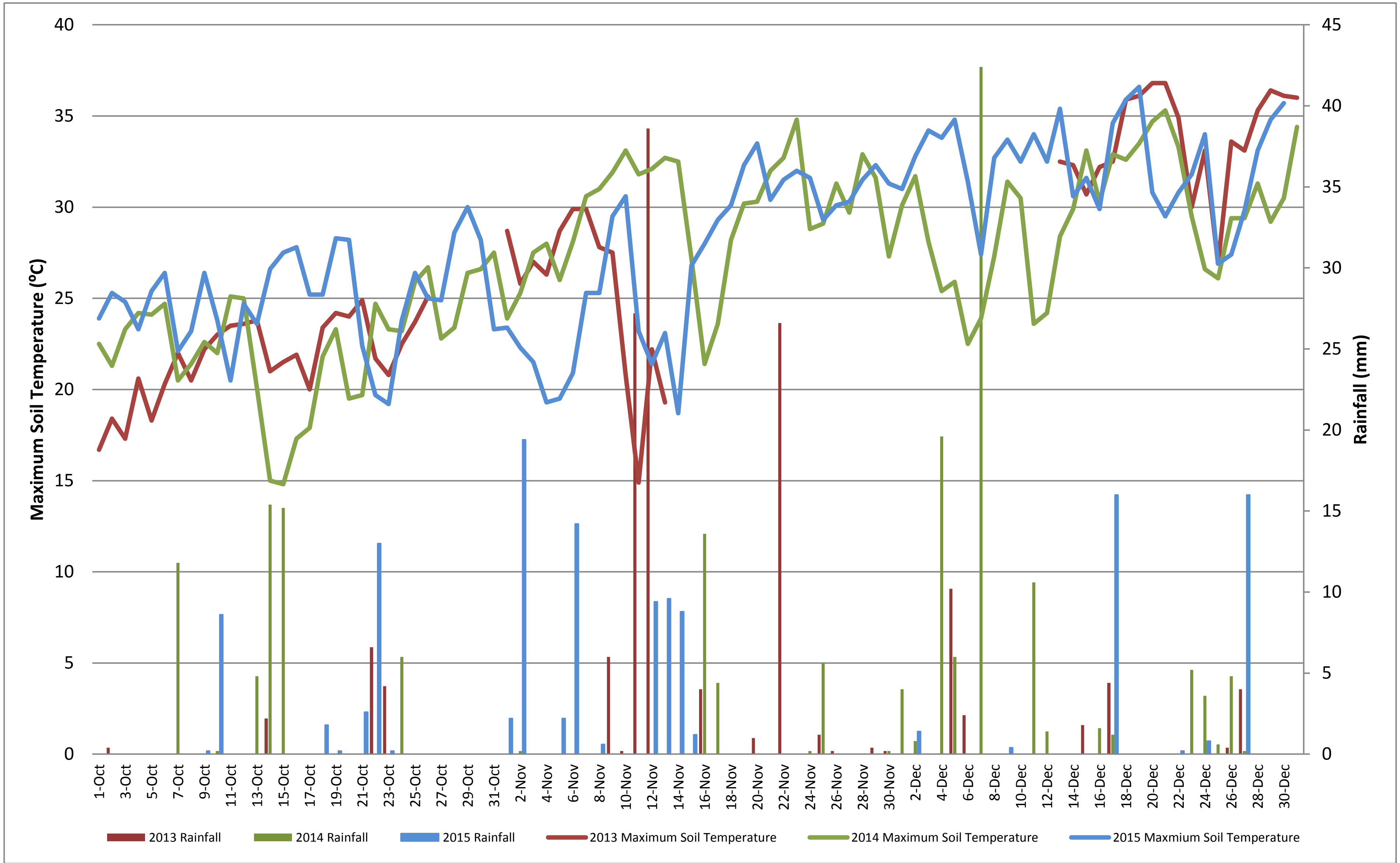

Figure 7. Maximum daily soil temperature and daily rainfall at Canberra Airport during the GSM flying period.

4. INTERPRETATION AND COMPARISON WITH PREVIOUS RESULTS

4.1 Ecological Interpretation

Winter shading of the impact zone of the York Park GSM site commenced in 2015; however, there were no changes in GSM flying moth activity, pupae case counts or vegetation condition, which were unlikely to be due to natural seasonal variation in conditions.

All flying moth surveys were undertaken during the peak period of GSM activity in the Canberra area and are consequently valid representations of GSM activity levels at the York Park GSM site. Flying moth numbers observed were consistently low to moderate during the surveys based on the semi-quantitative GSM site assessment method developed by David Hogg Pty Ltd (2010). Negligible difference was observed between GSM numbers observed during rotational point counts in the northern end and the southern end of York Park. Consistent with previous surveys, marginally greater GSM numbers were observed along the eastern transect than along the western transect.

Six GSM pupae cases were recorded during the pupae case surveys; four cases in the impact zone and two in the control zone (Figure 3). This represents a very low rate of detection despite applying approximately six times the survey effort recommended by Richter (2013). The pupae cases observed indicate that GSM are breeding within York Park, but the low number and scattered locations recorded do not permit any conclusions to be drawn as to whether GSM favour any part of York Park. These very low pupae case numbers are indicative of the generally low GSM numbers at York Park and the challenges when conducting pupae surveys, i.e. pupae case distribution is highly variable and unpredictable.

Quadrats varied in floristic value, diversity, vegetation cover and weed presence, but overall were indicative of degraded natural temperate grassland. Vegetation in three quadrats in the impact zones (Figure 3) had a floristic score of four, nominally meeting the criteria of Rehwinkel *et al.* (2007) for inclusion in the natural temperate grassland endangered ecological community. Floristic scores in the control zone were generally lower, with a 1.25 difference in the average floristic score from the impact to the control zones. Sites in the impact zone had marginally higher native and exotic species diversity compared to the control zone. No difference was recorded between vegetation cover for the impact and control zones. The lower diversity and floristic scores recorded in 2015 relative to 2014 is likely attributable to the substantially drier season and the late timing of the survey reducing the number of native forbs observed.

Overall, the year 3 baseline surveys demonstrate that GSM are present in low to moderate numbers at the York Park GSM site, with pupae cases detected at very low numbers, in both the control and impact areas. Vegetation surveys confirmed that the York Park GSM site supports partially degraded natural temperate grassland, the majority of which is potential GSM breeding habitat.

4.2 Comparison with Year 1 – Year 2 Baseline Data

1.1.1 Flying moth surveys

Flying moths numbers during the 2015 flying season (Figure 8) were generally lower than recorded in 2014 (RJPL 2015) but higher than recorded in 2013 (RJPL 2014b). For the transect surveys, the average number of moths observed per transect in the 2015 flying season was 9.4, less than 11.0 during the 2014 survey (RJPL 2015) but higher than 4.4 observed during the 2013 survey (RJPL 2014b). Similarly, the combined average number of moths observed per count at the central point in 2015 was 2.4, lower than 2014 survey (i.e. 7.7), but substantially greater than recorded during the 2013 survey (i.e. 0.9). These observation rates generally fall within the classification of low or low to moderate GSM activity based on the semi-quantitative GSM site assessment method developed by David Hogg Pty Ltd (2010).

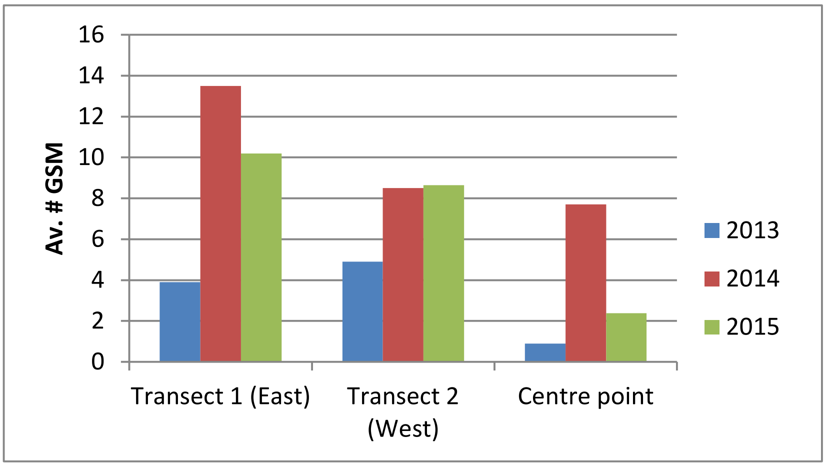

Figure 8. Average number of GSM observed on transect and centre point surveys by year.

As the surveys were conducted at similar points during the season and conditions were generally comparable, it is likely that this variation is due to natural seasonal variation in GSM activity. Previous studies conducted by Rowell (2012) and Ritcher (2013) on York Park found little variation with GSM densities over time, but detected moths in low abundance consistent with the present monitoring results. The variation observed in three years of monitoring observed lies consistently in the low to moderate activity range, and is consistent with previous reporting of little variation. It is likely that the variation observed is due to natural seasonal variation in GSM activity. This observation is consistent with evidence that GSM activity levels may be highly variable even when conditions are favourable (Hogg 2010).

Notable differences in conditions between years include exceptionally high rainfall in September and November 2013, and in December 2014 (Figure 2). Rainfall in 2015 was generally lower than in previous years be in September but increased in November. Average daily maxima were higher during September and October compared to 2014 in which the average maximum air temperatures were higher in October and November. 2015 had a greater average daily minimum air temperature compared to 2013 and 2014. Average daily maximum and minimum air temperatures were consistent in December from 2013 to2015 (Figure 3). Soil temperatures leading up to the GSM flying season were similar from 2013 to 2015 (Figure 4), however there is missing BoM data between mid-November and mid-December 2013, which limits comparison of these months between 2013 to 2015.

1.1.2 Pupae case surveys

The 2015 pupa case search result was the highest compared to 2014 and 2013 season (Figure 9), with six pupae cases recorded compared to five and two pupae cases recorded in 2014 and 2013 respectively. The detection rate is still very low and it is likely that the variation in pupae case detection between years, and between the control and impact sites is due to stochastic variation, despite the relatively high survey effort relative to the recommendations of Richter *et. al.* (2013). No conclusions can be drawn from the baseline data regarding the breeding success in the control and impact zones prior to any shading occurring using pupae case searches.

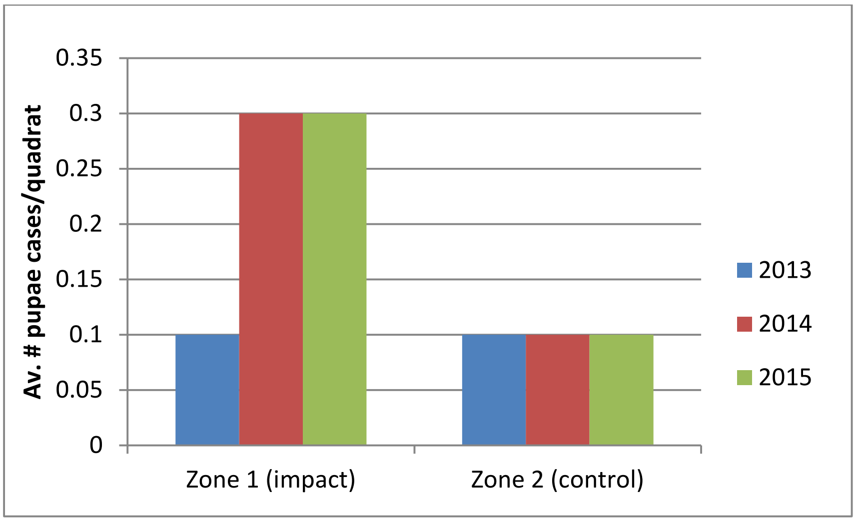

Figure 9. Average number of pupae cases observed by year.

1.1.3 Vegetation surveys

Figure 10 and Figure 11 show summarised vegetation survey results compared by year for the impact and control zones. The 2015 survey had lower average floristic value scores and lower native species diversity compared to either 2013 and 2014 vegetation assessment. This difference was more distinct in the control zone (Figure 11) than in the impact zone (Figure 10), and consequently cannot be attributed to shading impacts. The 2014 survey was conducted in October and consequently is likely to favour the detection of native forbs and exotic annuals relative to the surveys conducted in December for both the 2013 and 2015 season (RJPL 2014b).

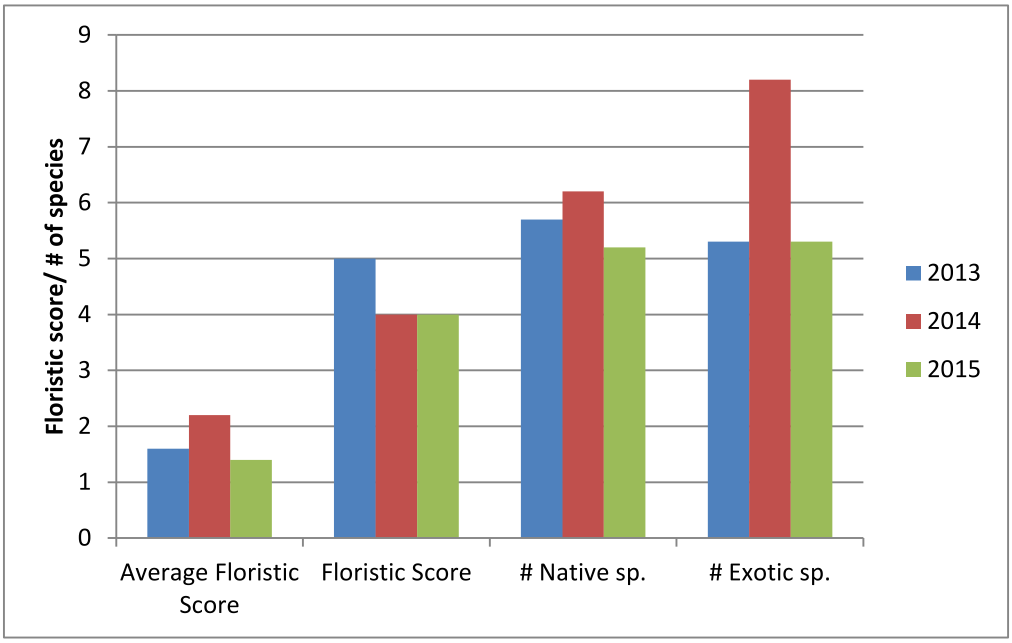

Figure 10. Comparison of impact zone vegetation statistics by year.

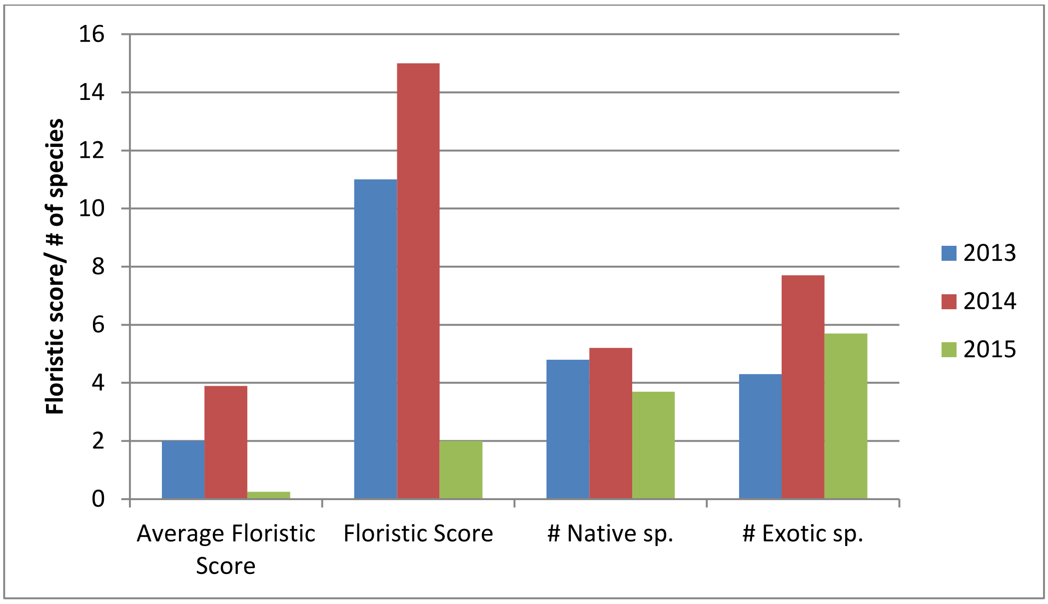

Figure 11. Comparison of control zone vegetation statistics by year.

Climate variability, in particular rainfall and seasonal variability, is an important factor in grassland composition and cover (Williams *et al*. 2015). In 2013, rainfall was 14% below the average (BOM 2013). In 2014, rainfall was still below average (BOM 2014). In 2015, rainfall was close to the average rainfall in comparison to previous years (BOM 2015). The increase in rainfall is likely to have affected the composition of native species and weeds. For exampling, in previous years, native species sensitive to climate variability, e.g. Bulbine Lily (*Bulbine bulbosa*) and Cut-leaf Goodenia (*Goodenia pinnatifida*), were identified but not in 2015. The absence of these species from the 2015 surveys does not suggest that these species no longer occur at the site, but most likely reflects very dry conditions and the late survey timing in 2015.

Variations in vegetation composition between the years may have occurred as precise quadrat locations are not been permanently marked out. Quadrats are marked by a GPS co-ordinate, resulting in a potential ±5 m error, and consequently quadrats may be located in slightly different positions each year. This has the potential to influence plant diversity recorded within each individual quadrat. The impact on analysis is anticipated to be minimal, as survey design does not require sampling of the same location and incorporates sampling of multiple quadrats within both the impact and control zones.

5. COMPLIANCE WITH THE GSM MONITORING PLAN

5.1 Survey Requirements

Transect surveys, pupae case surveys and vegetation surveys were conducted according to the methods specified in the monitoring plan (RJPL 2014a). Soil temperature loggers were successfully recovered from York Park; however, data was successfully recovered from only two of the four units.

As described in Section 3.5, the soil temperature loggers located in Zone 1a and Zone 2a failed due to password protection issues caused by a manufacturer's software update. Data could not be recovered from the devices. All the soil temperature loggers will need replacing. Comparison of soil temperature data from the two functioning loggers indicates that there was minimal soil temperature variation in York Park, with average daily variation typically within the 0.5˚C error of the loggers.

5.2 Reporting Requirements

The GSM monitoring plan (RJPL 2014a) requires that annual monitoring reports meet the following specifications:

- Annual monitoring and compliance reports would be prepared in a timely manner each year meeting the *EPBC Act* approval requirements (Conditions 3, 8) by:
    - providing and assessing the monitoring data for the previous twelve months against the baseline conditions
    - concluding whether or not there has been a decline in the GSM population in the area of York Park shaded as a result of the action, taking into account regional population trends and local ecological conditions
    - reviewing the GSMMP's applicability in achieving its objectives (Condition 8) to determine whether, under *EPBC Act* approval Condition 10, the GSMMP should be revised in consultation with the Commonwealth.
- When preparing the report, reference would be made to the current NTGMP and any relevant management and monitoring changes relevant to a review of this GSMMP.

The current report represents the third baseline data monitoring report. The above requirements for analysis against the baseline conditions and assessment of whether there has been a decline in the population of GSM at York Park can only be qualitatively assessed as additional data is required.

The preparation of this report fulfils the reporting requirements for year 3 baseline surveys as specified in the monitoring plan (RJPL 2014a).

5.3 Potential Compliance Issues

Data could not be recovered from two soil temperature loggers due to a software fault resulting from a manufacturer's upgrade. Comparable data is available to be used in place of the lost data, and, while DoE should be notified of this issue, SMEC does not consider that the logger fault represents a compliance issue in relation to the approval. Due to the failure of these two data loggers, and similar issues with failure of one data logger in 2014, SMEC recommends that a new, more reliable, model of soil temperature data logger be sourced and installed before winter.

5.4 GSM Monitoring Plan Review

Monitoring of flying moth numbers and vegetation condition is progressing according to the GSM monitoring plan, and the data collected is appropriate for the analyses proposed to commence after the fifth flying season. In contrast, the current monitoring results suggest that the effectiveness of pupae case surveys and ongoing soil temperature monitoring may be limited, and requires reconsideration in consultation with DoE. These issues and the proposed responses are summarised in Table 5-1.

Pupae cases have consistently been detected at very low rates in the quadrats, despite the substantially higher survey effort implemented relative to the recommendations of Richter *et. al.* (2013). The very low detection rate is such that it is highly unlikely that any trends in pupae case numbers will be detected, and no meaningful BACI analysis of changes in pupae case numbers can be applied. Due to the uninformative nature of this data, the BACI analysis of pupae case numbers proposed in the GSM monitoring plan is not feasible and we propose that pupae case sampling be discontinued and that monitoring focuses on flying GSM and the comparison of vegetation condition in the control and impact zones.

While there have been some difficulties with soil temperature monitoring, preliminary results indicate that there is negligible difference in soil temperature during the shading period between the control and impact areas. If this is the case, ongoing collection of soil temperature data will not be informative to future analyses. We recommend that this be confirmed through one more complete season of monitoring, and, if verified soil temperature monitoring can then be discontinued.

Table 5-1. Recommended changes to the GSM monitoring plan.

	Issue	Proposed response
Pupae Case Counts	The detection of moth pupae cases is insufficient for comparison of trends in shaded or non-shaded areas	End pupae case sampling in quadrats. Monitoring should focus on general trends in flying GSM numbers across York Park and a comparison of vegetation condition in the control and impact zones.
Soil Temperature Monitoring	Difference in soil temperature during the winter shading period between control and impact sites is less than the ±0.5˚C recording error of the loggers, indicating that shading impacts on soil temperature are negligible. This result is unlikely to change over time as the impact site was fully shaded in winter 2015.	Continue soil temperature monitoring for one more complete season. If there is no substantial difference (i.e. >1˚C) between impact and control zone soil temperatures during the winter shading period after one more complete monitoring period, we recommend that the soil temperature monitoring component be discontinued.

SMEC recommends that discussions with DoE be held prior to winter 2016 and the GSM flying season to determine the best approach to the issues identified in Table 5-1, and to reach agreement on any amendments to the GSM monitoring plan.

6. CONCLUSION

This report provides baseline results of flying moth surveys, pupae case surveys and vegetation surveys for 2015 in accordance with the *Potential shading impacts on York Park golden sun monitoring plan* (RJPL 2014a, the monitoring plan). Data is provided in summarised form suitable for incorporation into future analyses of potential impacts. Appendices A to D present all survey data.

The surveys confirmed the presence of GSM at low to moderate activity levels in the York Park GSM site, confirmed the low pupae case detection rates and confirmed the vegetation classification in the York Park GSM site as natural temperate grassland. Vegetation condition was generally consistent between the control and impact zones although variation was present between quadrats.

Soil temperature loggers were recovered and data downloaded from two of the four zones. The loggers located in Zone 1a and Zone 2a were faulty and due to the issue with the software, all the data loggers need to be replaced. Analysis of data from the two working data loggers indicates a low level of variation between loggers.

2015 represents the third year of data collection. Winter shading of the impact zone of the York Park GSM site commenced in 2015. Basic comparison of results of flying moth surveys and vegetation condition surveys with the first year and second year of baseline data (RJPL 2014b) did not identify any dramatic changes potentially resulting from winter shading of the site, but is consistent with the high level of seasonal variability in the levels of GSM activity detected and a moderate level of variability in vegetation condition. Consistent with the three earlier seasons, pupae case detection rates are too low to enable the proposed BACI analysis to be meaningfully undertaken after the fifth survey season. Despite shading occurring during the winter period of 2015, negligible difference in soil temperatures between the impact and control areas was recorded.

Surveys were conducted in a manner consistent with the survey requirements outlined in the monitoring plan (RJPL 2014a). This report also fulfils requirements for reporting the year 3 baseline monitoring data outlined in the monitoring plan (RJPL 2014a).

SMEC recommends that data loggers be replaced with a more reliable model prior to winter 2016. In addition, discussions with the DoE should be undertaken to review the following recommended amendments to the GSM monitoring plan:

- the pupae case surveys and associated analyses should be removed from the monitoring plan as detection of pupae cases is insufficient for meaningful analysis
- the importance of monitoring soil temperatures should be reviewed after one additional full season of monitoring, and, if there is no substantial difference in soil temperatures within shaded and unshaded areas after this period, temperature monitoring be removed from the monitoring plan.

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APPENDIX A: FLYING MOTH SURVEY 2014 AND 2015

Appendix A - Table 1: Flying moth surveys 2015 – transects.

Date	Transect	Moth numbers / Survey time			Moth numbers
		1130	1200	1230	Average (1dp)
19/11/2015	Transect 1	6	14	22	10.6
25/11/2015	Transect 1	7	12	10	9.723
112/2015	Transect 1	1	7	23	10.3
19/11/2015	Transect 2	11	12	23	15.3
25/11/2015	Transect 2	3	3	4	3.3
1/12/2015	Transect 2	4	8	10	7.3

Appendix A - Table 2: Flying moth surveys 2015 – point observations.

Date	Time	Point	Moth numbers	
			Average (1dp)	Range
19/11/2015	11:30	North	1.1	0-3
25/11/2015	11:40	North	2.1	0-5
1/12/2015	11:50	North	1.1	1-2
19/11/2015	11:43	Centre	2.8	0-8
25/11/2015	11:36	Centre	1.8	0-5
1/12/2015	11:38	Centre	1.2	0-2
19/11/2015	12:15	Centre	4.7	1-12
25/11/2015	12:36	Centre	-	-
1/12/2015	12:09	Centre	1.4	0-5
19/11/2015	11:55	South	2.1	0-7
25/11/2015	12:05	South	2.1	0-5
1/12/2015	12:20	South	1.9	0-4

APPENDIX B: PUPAE CASE SURVEY 2015

Date	Survey	Quadrat	Control or Impact site	Zone	Pupae case numbers	Notes
25/11/2015	1	1	Impact	1a	0	
25/11/2015	1	2	Impact	1a	0	
25/11/2015	1	3	Impact	1a	0	
25/11/2015	1	4	Impact	1a	0	
25/11/2015	1	5	Impact	1a	0	
25/11/2015	1	6	Impact	1a	2	
25/11/2015	1	7	Impact	1a	0	
25/11/2015	1	8	Impact	1a	0	
25/11/2015	1	9	Impact	1a	1	
25/11/2015	1	10	Impact	1b	0	
25/11/2015	1	11	Impact	1b	0	
25/11/2015	1	12	Impact	1b	0	
25/11/2015	1	13	Control	2b	0	
25/11/2015	1	14	Control	2b	0	
25/11/2015	1	15	Control	2a	0	
25/11/2015	1	16	Control	2a	0	
25/11/2015	1	17	Control	2a	1	
25/11/2015	1	18	Control	2a	0	
25/11/2015	1	19	Control	2a	0	
25/11/2015	1	20	Control	2b	0	
25/11/2015	1	21	Control	2a	0	
25/11/2015	1	22	Control	2a	0	
25/11/2015	1	23	Control	2a	0	
25/11/2015	1	24	Control	2a	0	
01/12/2015	2	1	Impact	1a	0	
01/12/2015	2	2	Impact	1a	0	
01/12/2015	2	3	Impact	1a	0	
01/12/2015	2	4	Impact	1a	0	
01/12/2015	2	5	Impact	1a	0	
01/12/2015	2	6	Impact	1a	0	
01/12/2015	2	7	Impact	1a	0	
01/12/2015	2	8	Impact	1a	0	
01/12/2015	2	9	Impact	1a	0	
01/12/2015	2	10	Impact	1b	0	
01/12/2015	2	11	Impact	1b	0	
01/12/2015	2	12	Impact	1b	0	
01/12/2015	2	13	Control	2b	0	
01/12/2015	2	14	Control	2b	0	
01/12/2015	2	15	Control	2a	0	
01/12/2015	2	16	Control	2a	0	
01/12/2015	2	17	Control	2a	0	
01/12/2015	2	18	Control	2a	0	.

Date	Survey	Quadrat	Control or Impact site	Zone	Pupae case numbers	Notes
01/12/2015	2	19	Control	2a	0	
01/12/2015	2	20	Control	2b	0	
01/12/2015	2	21	Control	2a	0	
01/12/2015	2	22	Control	2a	1	
01/12/2015	2	23	Control	2a	0	
01/12/2015	2	24	Control	2a	0	
15/12/2015	3	1	Impact	1a	0	
15/12/2015	3	2	Impact	1a	0	
15/12/2015	3	3	Impact	1a	0	
15/12/2015	3	4	Impact	1a	0	
15/12/2015	3	5	Impact	1a	0	
15/12/2015	3	6	Impact	1a	0	
15/12/2015	3	7	Impact	1a	0	
15/12/2015	3	8	Impact	1a	0	
15/12/2015	3	9	Impact	1a	0	
15/12/2015	3	10	Impact	1b	0	
15/12/2015	3	11	Impact	1b	1	
15/12/2015	3	12	Impact	1b	0	
15/12/2015	3	13	Control	2b	0	
15/12/2015	3	14	Control	2b	0	
15/12/2015	3	15	Control	2a	0	
15/12/2015	3	16	Control	2a	0	
15/12/2015	3	17	Control	2a	0	
15/12/2015	3	18	Control	2a	0	
15/12/2015	3	19	Control	2a	0	
15/12/2015	3	20	Control	2b	0	
15/12/2015	3	21	Control	2a	0	
15/12/2015	3	22	Control	2a	0	
15/12/2015	3	23	Control	2a	0	
15/12/2015	3	24	Control	2a	0	

APPENDIX C: VEGETATION SURVEY 2015

Date	Quadrat	Control or Impact site	Zone	Species (* - exotic species)		Cover (%)
				Dominant	Co-Dominant	
16/10/2014	1	Impact	1a	*Austrostipa bigeniculata*		70
16/10/2014	2	Impact	1a	*Austrostipa bigeniculata*		60
16/10/2014	3	Impact	1a	*Austrostipa bigeniculata*		50
16/10/2014	4	Impact	1a	*Austrostipa bigeniculata*	*Bothriochloa macra*	70
16/10/2014	5	Impact	1a	*Austrostipa bigeniculata*	*Bothriochloa macra*	85
16/10/2014	6	Impact	1a	*Austrostipa bigeniculata*	*Bothriochloa macra*	90
16/10/2014	7	Impact	1a	*Austrostipa bigeniculata*	*	80
16/10/2014	8	Impact	1a	*Themeda triandra*		70
16/10/2014	9	Impact	1a	*Bothriochloa macra*		80
16/10/2014	10	Impact	1b	*Austrostipa bigeniculata*	*Bothriochloa macra*	80
16/10/2014	11	Impact	1b	*Austrostipa bigeniculata*	*Bothriochloa macra*	75
16/10/2014	12	Impact	1b	*Austrostipa bigeniculata*	*Austrostipa scabra*	95
16/10/2014	13	Control	2b	*Austrostipa bigeniculata*		70
16/10/2014	14	Control	2b	*Austrostipa bigeniculata*		60
16/10/2014	15	Control	2a	*Austrostipa bigeniculata*	*Bothriochloa macra*	70
16/10/2014	16	Control	2a	*Austrostipa bigeniculata*	*Bothriochloa macra*	95
16/10/2014	17	Control	2a	*Austrostipa bigeniculata*	*Austrostipa scabra*	90
16/10/2014	18	Control	2a	*Bothriochloa macra*		80
16/10/2014	19	Control	2a	*Austrostipa bigeniculata*	*Bothriochloa macra*	95
16/10/2014	20	Control	2b	*Dactylis glomerata**	*Bothriochloa macra*	65
16/10/2014	21	Control	2a	*Austrostipa bigeniculata*		80
16/10/2014	22	Control	2a	*Austrostipa bigeniculata*	*Bothriochloa macra*	80
16/10/2014	23	Control	2a	*Austrostipa bigeniculata*		80
16/10/2014	24	Control	2a	*Austrostipa bigeniculata*		60

Scientific name	Common name	Quadrat number																							
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Native grasses																									
Aristida ramosa	Wiregrass						+																		
Austrodanthonia auriculata	Lobed Wallaby Grass																								
Austrodanthonia bipartita	A Wallaby Grass																								
Austrodanthonia caespitosa	Ringed Wallaby Grass																								
Austrodanthonia carphoides	Short Wallaby Grass																								
Austrodanthonia fulva	A Wallaby Grass																								
Austrodanthonia laevis	Smooth Wallaby Grass																								
Austrodanthonia spp.	Wallaby Grasses		+			+	+	+	1		+			r		2	+	2	2			+	2		
Austrostipa bigeniculata	Tall Speargrass	4	3	3	3	4	+	5			4	3	4	4	4	3	4	4		4	2	5	2	5	4
Austrostipa densiflora	A Speargrass																								
Austrostipa scabra	Rough Speargrass			+			4		1		+		2		2		3	r							
Bothriochloa macra	Redleg Grass	r	2		3	2	3	2		4	2	2	2	r	2	3	3	2	5	3	3	2	4	2	
Chloris truncata	Windmill Grass																							r	
Elymus scaber	Wheatgrass					+		r					r												
Eragrostis brownii	A Lovegrass																								
Eragrostis trachycarpa	A Lovegrass																								
Microlaena stipoides	Weeping Grass	r																							
Panicum effusum	Hairy Panic Grass			r			+		r				+	r	+		+	+		r		2	2		
Poa labillardieri	Tussock Grass																								
Themeda triandra	Kangaroo Grass								4																
Native forbs																									
Acaena ovina	Sheeps Burr																								
Asperula conferta[2]	Common Woodruff																								
Bulbine bulbosa[2]	Golden Lily																								
Calocephalus citreus[2]	Lemon Beauty Heads																								
Chamaesyce drummondii	Caustic Weed																								

Scientific name	Common name	Quadrat number																							
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Cheilanthes sp. [2]																r									
Cheilanthes sieberi[2]	Rock Fern																								
Cheilanthes tenuifolia[2]																									
Chenopodium pumilio	Small Crumbweed																								
Chrysocephalum apiculatum[1]	Yellow Buttons	+	2			1	2		+	r	r	+	+			2									
Chrysocephalum semipapposum	Clustered Everlasting												+												
Convolvulus angustissimus	Australian Bindweed									r		r													
Crassula sieberiana	Australian Stonecrop																								
Cymbonotus lawsonianus	Bear's Ears																								
Drosera peltata	Sundew																								
Eryngium rostratum[2]	Blue Devil																								
Euchiton sp.	A Cudweed																								
Euchiton gymnocephalus	A Cudweed																								
Euchiton sphaericus	A Cudweed																								
Glycine tabacina[2]	Vanilla Glycine																								
Gonocarpus tetragynus[1]	Raspwort																								
Goodenia pinnatifida[2]	Scrambled Eggs	r																							
Hypericum gramineum[2]	Small St John's Wort																								
Juncus sp.	A Rush																								
Lomandra bracteata[1]	A Matrush																			r					
Lomandra filiformis[1]	A Matrush																								
Lomandra multiflora[2]	A Matrush																								
Lomandra sp. [1]	A Matrush			r																					
Microtis unifolia[2]	Common Onion Orchid																								
Oxalis perennans	Soursob																								
Pimelea curviflora[2]	Curved Rice-flower																								
Plantago varia[2]	Variable Plantain																								
Rumex brownii	Swamp Dock																								
Schoenus apogon	Bog-rush		r	r	r																				

Scientific name	Common name	Quadrat number																							
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Sebaea ovata[2]																									
Senecio quadridentatus	Cotton Fireweed																								
Solenogyne dominii	Smooth Solenogyne																								
Stackhousia monogyna[2]	Creamy Candles														r										
Tricoryne elatior[2]	Yellow Rush Lily						+																		
Triptilodiscus pygmaeus[2]	Austral Sunray																								
Vittadinia muelleri	Fuzzweed																								
Wahlenbergia sp.	A Bluebell																								
Wahlenbergia communis	Tufted Bluebell																								
Wahlenbergia luteola	A Bluebell																								
Wahlenbergia stricta	Tall Bluebell																								
Wurmbea dioica[2]	Early Nancy																								
Xerochrysum viscosum[2]	Sticky Everlasting																								
Exotic grasses																									
Aira sp.	A Hairgrass											+												+	
Aira elegantissima	A Hairgrass																								
Avena sp.	Wild Oats	r			+	r						r	r	r			+	r						r	r
Avena barbata	Bearded Oats																								
Briza maxima	Blowfly Grass	r	+	r	1	1	+	+	+	1	+	1	+	r	+	r	1	1	+	+	+	1	+	1	+
Briza minor	Shivery Grass																								
Bromus sp.	A Brome Grass																								
Bromus catharticus	A Brome Grass																								
Bromus diandrus	A Brome Grass																								
Bromus hordeaceus	A Brome Grass																								
Bromus mollis	Soft Brome																								
Cynodon dactylon	Couch		r		+										r		+								
Dactylis glomerata	Cocksfoot	2		r										2		r									
Eleusine tristachya	Goose Grass																								
Eragrostis curvula	African Lovegrass																								

Scientific name	Common name	Quadrat number																							
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Festuca sp.	A Fine-leaved Fescue																								
Festuca arundinacea	Tall Fescue																								
Lolium perenne	Perennial Ryegrass																								
Lolium rigidum	Ryegrass																								
Lophochloa cristata	Annual Cat's Tail																								
Nassella neesiana	Chilean Needlegrass																								
Nassella trichotoma	Serrated Tussock																								
Paspalum dilatatum	Paspalum																								
Phalaris aquatica	Phalaris																								
Poa bulbosa	Bulbous bluegrass																								
Vulpia sp.	Rat's-tail Fescue	r	r										r	r	r										r
Exotic forbs																									
Acetosella vulgaris	Sorrel																								
Anagallis arvensis	Scarlet Pimpernel																								
Arctotheca calendula	Capeweed																								
Centaurium erythraea	Pink Stars		r	r		+	r	r	+	r	r	+			r	r		+	r	r	+	r	r	+	
Centaurium tenuiflorum	*Branched Centaury*		*r*	*r*	+	+	+		*r*				+		*r*	*r*	+	+	+		*r*				+
Cerastium glomeratum	Chickweed																								
Cirsium vulgare	Spear Thistle																								
Conyza bonariensis	Flax-leaf Fleabane																								
Echium plantagineum	Paterson's Curse																								
Erodium cicutarium	Common Crowfoot																								
Galium divaricatum	A Bedstraw																								
Gamochaeta purpurea	A Cudweed																								
Gnaphalium sp.	A Cudweed																								
Hirschfeldia incana	Hoary Mustard																								
Hypericum perforatum	St John's Wort				+		r	r					r				+		r	r					r
Hypochaeris glabra	Smooth Catsear																								
Hypochaeris radicata	Catsear		1		+	+	+	+			+		r		1		+	+	+	+			+		r

Scientific name	Common name	Quadrat number																							
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Lactuca serriola	Prickly Lettuce																								
Lepidium africanum	A Peppercress																								
Parentucellia latifolia	Common Bartsia																								
Petrorhagia nanteulii	Proliferous Pink																								
Plantago lanceolata	Ribwort Plantain	+		r	r		+	r	+	r	r	+	r	+		r	r		+	r	+	r	r	+	r
Romulea rosea	Onion Grass																								
Salvia verbenaca	Wild Sage																								
Silene gallica	French Catchfly																								
Sonchus oleraceus	Common Sow-thistle																								
Tragopogon porrifolius	Salsify																								
Trifolium angustifolium	Narrow leaf Clover																								
Trifolium arvense	Haresfoot Clover			r					r	2						r					r	2			
Trifolium campestre	Hop Clover																								
Trifolium dubium								r												r					
Trifolium glomeratum	Clustered Clover																								
Trifolium striatum																									
Trifolium spp.	Clovers																								
Exotic shrubs and trees																									
Cotoneaster sp.	Cotoneaster																								
Crataegus monogyna	Hawthorn																								
Ligustrum sinense	Small-leaved Privet																								
Populus nigra var. *italica*	Lombardy Poplar																								
Prunus sp.	Plum																								
Sorbus domestica	Service Tree																								

Indicator	Quadrat number																						
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24

Number of Common Species	3	5	4	4	4	6	5	3	2	4	3	6	4	4	3	5	5	2	3	2	4	4	3	1
Number of indicator level 1 species	1	1	0	0	1	1	0	1	1	1	1	1	0	0	1	0	0	0	1	0	0	0	0	0
Number of indicator level 2 species	1	0	0	0	0	1	0	1	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0
Total number of native species	5	6	4	4	5	8	5	5	3	5	4	9	4	5	5	5	5	2	4	2	4	4	3	1
Number of exotic species	5	4	6	6	5	6	7	5	4	4	5	6	5	7	4	8	8	7	4	4	5	6	2	6
Number of significant weed species	0	0	0	1	0	1	1	0	0	0	0	1	0	1	0	1	0	0	0	0	0	0	0	0
Site value score	2	**1**	**0**	0	1	**4**	**0**	4	0	**0**	**1**	**4**	0	**1**	**2**	0	0	**0**	0	0	0	0	**0**	**0**

APPENDIX D: DAILY MAXIMUM AND MINIMUM SOIL TEMPERATURES

No data is provided for Zone 1a or 2a as the loggers was faulty and no data could be recovered. Discussion from the wholesaler identified that since the last download, an update in the software has caused some data loggers to be locked with a password and retrieving data from these temperature loggers is not possible. As the definition of Zones 1b and 2b is based on potential shading from development on Block 3 Section 22 Barton, which has not occurred to date, data monitors in these zones can be considered to have been subjected to the same shading treatments as Zones 1a and 2a respectively.

Date	Zone 1b Daily Min (˚C)	Zone 1b Daily Max (˚C)	Zone 2b Daily Min (˚C)	Zone 2b Daily Max (˚C)
20-Oct-14	12.12	22.64	12.09	22.61
21-Oct-14	11.12	19.13	11.09	19.11
22-Oct-14	14.63	22.64	15.6	24.11
23-Oct-14	15.63	21.14	16.6	22.61
24-Oct-14	15.63	22.64	16.6	24.11
25-Oct-14	16.13	24.14	16.6	25.61
26-Oct-14	17.13	25.14	17.6	26.61
27-Oct-14	16.63	20.64	17.6	22.11
28-Oct-14	14.63	23.14	15.6	25.11
29-Oct-14	15.13	24.64	16.6	26.61
30-Oct-14	15.63	24.64	16.6	26.61
31-Oct-14	15.63	25.14	17.1	27.11
1-Nov-14	17.13	22.14	18.61	24.11
2-Nov-14	14.13	24.14	15.6	26.11
3-Nov-14	14.63	25.14	16.1	26.61
4-Nov-14	17.63	26.14	19.11	28.11
5-Nov-14	17.63	23.64	19.11	25.61
6-Nov-14	18.13	25.64	19.61	27.11
7-Nov-14	17.13	27.14	18.61	29.11
8-Nov-14	17.63	28.14	19.11	30.11
9-Nov-14	18.13	28.64	19.61	30.61
10-Nov-14	20.64	29.64	22.11	31.61
11-Nov-14	20.14	29.14	21.61	31.11
12-Nov-14	20.14	29.14	22.11	31.11
13-Nov-14	20.64	29.64	22.61	31.61
14-Nov-14	20.14	30.14	22.11	32.6
15-Nov-14	20.64	24.64	22.61	26.11
16-Nov-14	18.13	21.14	18.61	23.11
17-Nov-14	16.13	24.64	17.1	27.61
18-Nov-14	16.63	26.14	18.1	28.11
19-Nov-14	19.13	28.14	20.11	30.11
20-Nov-14	18.13	27.64	19.61	29.11
21-Nov-14	20.14	28.14	21.61	30.11
22-Nov-14	21.14	30.14	22.11	32.1

Date	Zone 1b Daily Min (˚C)	Zone 1b Daily Max (˚C)	Zone 2b Daily Min (˚C)	Zone 2b Daily Max (˚C)
23-Nov-14	20.64	31.63	22.11	33.6
24-Nov-14	21.64	25.14	22.61	26.61
25-Nov-14	19.64	28.64	21.11	30.61
26-Nov-14	18.63	29.14	19.61	30.61
27-Nov-14	21.14	30.14	22.11	31.11
28-Nov-14	19.64	30.64	21.11	32.1
29-Nov-14	20.64	29.64	22.11	30.61
30-Nov-14	21.64	26.64	22.61	27.61
1-Dec-14	19.64	30.64	20.61	31.61
2-Dec-14	21.14	30.14	22.61	31.61
3-Dec-14	21.64	26.64	22.11	27.61
4-Dec-14	20.64	26.64	21.61	27.61
5-Dec-14	20.64	28.14	21.11	29.11
6-Dec-14	20.14	22.64	20.61	23.61
7-Dec-14	18.63	26.64	19.11	28.11
8-Dec-14	19.64	26.64	20.11	28.11
9-Dec-14	21.14	30.14	21.61	30.61
10-Dec-14	22.14	28.14	22.61	29.11
11-Dec-14	20.14	23.64	20.61	24.11
12-Dec-14	18.13	24.64	19.11	25.61
13-Dec-14	19.13	27.14	20.11	28.11
14-Dec-14	18.63	27.64	19.61	28.11
15-Dec-14	19.64	29.64	20.11	30.11
16-Dec-14	21.64	29.14	22.61	30.11
17-Dec-14	20.14	29.64	21.11	30.11
18-Dec-14	21.14	30.64	22.11	31.11
19-Dec-14	20.14	30.14	21.11	31.11
20-Dec-14	21.64	31.14	22.61	32.1
21-Dec-14	22.64	32.13	23.61	32.6
22-Dec-14	23.14	29.14	24.11	30.11
23-Dec-14	22.14	29.64	23.11	30.61
24-Dec-14	22.64	26.64	23.61	26.61
25-Dec-14	22.14	26.64	22.61	27.11
26-Dec-14	21.14	29.14	21.61	30.61
27-Dec-14	20.14	28.64	21.11	29.11
28-Dec-14	20.14	28.64	21.11	28.61
29-Dec-14	20.64	27.64	21.61	28.61
30-Dec-14	19.64	30.14	20.61	30.61
31-Dec-14	20.14	31.63	21.11	32.1
1-Jan-15	23.64	33.13	24.11	33.6
2-Jan-15	22.64	34.63	23.61	34.6
3-Jan-15	24.64	35.13	25.61	35.6
4-Jan-15	25.14	31.14	26.11	31.61
5-Jan-15	22.64	32.63	23.61	32.6

Date	Zone 1b Daily Min (˚C)	Zone 1b Daily Max (˚C)	Zone 2b Daily Min (˚C)	Zone 2b Daily Max (˚C)
6-Jan-15	23.14	29.64	24.11	30.11
7-Jan-15	22.14	29.64	22.61	30.11
8-Jan-15	22.14	31.63	23.11	32.1
9-Jan-15	24.14	30.64	24.61	31.11
10-Jan-15	23.14	27.14	23.61	27.11
11-Jan-15	21.64	24.64	22.11	25.11
12-Jan-15	21.14	27.64	21.61	28.11
13-Jan-15	21.64	24.64	22.11	25.11
14-Jan-15	21.64	27.64	21.61	28.11
15-Jan-15	20.64	28.64	21.11	29.61
16-Jan-15	21.14	29.14	21.61	29.61
17-Jan-15	20.64	29.14	21.11	29.61
18-Jan-15	20.14	29.14	20.61	29.11
19-Jan-15	22.14	28.64	22.11	28.61
20-Jan-15	22.14	26.64	22.11	26.11
21-Jan-15	22.14	27.64	22.11	27.61
22-Jan-15	21.64	29.64	21.61	29.61
23-Jan-15	22.64	30.64	23.11	31.11
24-Jan-15	23.64	29.64	24.11	30.11
25-Jan-15	22.64	29.64	23.11	30.61
26-Jan-15	22.14	27.14	22.61	27.11
27-Jan-15	20.64	22.14	21.11	22.61
28-Jan-15	19.64	25.14	20.11	25.11
29-Jan-15	19.13	25.64	19.11	25.61
30-Jan-15	18.63	23.14	18.61	23.61
31-Jan-15	18.13	26.14	18.61	26.11
1-Feb-15	19.64	26.14	20.11	26.11
2-Feb-15	19.13	24.64	19.61	25.11
3-Feb-15	18.13	26.64	18.61	27.11
4-Feb-15	19.64	22.64	19.61	23.11
5-Feb-15	18.63	27.14	19.11	27.11
6-Feb-15	19.64	28.64	20.11	28.61
7-Feb-15	20.64	29.64	21.11	29.11
8-Feb-15	21.64	29.14	22.11	29.11
9-Feb-15	22.14	25.14	22.61	25.61
10-Feb-15	21.64	29.64	22.11	29.61
11-Feb-15	23.14	30.64	23.61	31.11
12-Feb-15	23.64	27.64	24.11	28.11
13-Feb-15	22.64	28.14	23.11	29.11
14-Feb-15	21.64	25.14	22.11	25.61
15-Feb-15	21.14	27.64	21.61	28.11
16-Feb-15	21.14	28.64	21.61	29.11
17-Feb-15	22.64	31.63	23.11	31.61
18-Feb-15	23.14	30.64	23.61	31.11

Date	Zone 1b Daily Min (˚C)	Zone 1b Daily Max (˚C)	Zone 2b Daily Min (˚C)	Zone 2b Daily Max (˚C)
19-Feb-15	23.14	30.14	23.61	30.11
20-Feb-15	23.14	29.64	23.61	30.11
21-Feb-15	22.64	29.14	23.11	29.61
22-Feb-15	22.64	30.14	23.11	30.61
23-Feb-15	23.64	32.63	23.61	32.6
24-Feb-15	22.64	26.64	23.11	27.61
25-Feb-15	21.64	23.64	21.61	24.11
26-Feb-15	20.64	25.14	20.61	25.61
27-Feb-15	20.64	27.64	20.61	28.11
28-Feb-15	21.64	28.14	21.61	28.61
1-Mar-15	21.14	26.64	21.11	27.11
2-Mar-15	19.13	27.64	19.11	27.61
3-Mar-15	21.14	26.14	21.11	26.61
4-Mar-15	21.64	28.14	22.11	28.61
5-Mar-15	20.14	28.14	20.11	28.11
6-Mar-15	19.13	27.14	19.61	27.61
7-Mar-15	19.13	27.64	19.61	27.61
8-Mar-15	20.64	29.14	21.11	29.61
9-Mar-15	20.14	29.14	20.61	29.11
10-Mar-15	20.64	29.64	21.11	29.61
11-Mar-15	22.64	30.64	23.11	30.61
12-Mar-15	21.64	30.14	22.11	30.11
13-Mar-15	21.64	25.64	22.11	26.11
14-Mar-15	19.13	27.64	20.11	27.61
15-Mar-15	20.64	28.64	21.11	28.61
16-Mar-15	19.13	28.14	19.61	27.61
17-Mar-15	20.14	25.64	20.61	25.61
18-Mar-15	20.14	27.14	20.61	28.11
19-Mar-15	18.63	27.64	19.11	28.11
20-Mar-15	19.64	28.64	20.11	28.61
21-Mar-15	19.64	27.14	20.11	27.11
22-Mar-15	20.64	24.14	21.11	24.11
23-Mar-15	19.13	25.64	19.11	26.11
24-Mar-15	19.13	24.64	19.11	25.11
25-Mar-15	16.63	23.14	16.6	23.61
26-Mar-15	16.13	23.14	16.6	24.11
27-Mar-15	15.13	22.64	15.6	23.61
28-Mar-15	14.63	23.14	15.1	23.61
29-Mar-15	15.63	23.14	16.1	23.11
30-Mar-15	16.13	20.14	16.1	20.11
31-Mar-15	15.13	23.14	15.6	23.11
1-Apr-15	16.63	24.64	17.1	24.61
2-Apr-15	18.13	21.64	18.61	21.61
3-Apr-15	18.13	20.14	18.1	20.61

Date	Zone 1b Daily Min (˚C)	Zone 1b Daily Max (˚C)	Zone 2b Daily Min (˚C)	Zone 2b Daily Max (˚C)
4-Apr-15	17.63	19.13	18.1	19.11
5-Apr-15	16.63	22.14	17.1	22.11
6-Apr-15	15.63	18.63	15.6	19.11
7-Apr-15	12.62	17.13	11.59	17.6
8-Apr-15	11.12	15.13	10.59	15.1
9-Apr-15	12.62	18.63	12.09	18.61
10-Apr-15	14.63	18.13	14.1	18.61
11-Apr-15	13.62	19.13	13.6	19.61
12-Apr-15	14.13	19.64	14.1	19.61
13-Apr-15	14.63	19.64	14.6	19.61
14-Apr-15	14.63	18.13	14.6	18.61
15-Apr-15	14.63	18.13	15.1	18.61
16-Apr-15	14.63	20.64	14.6	21.11
17-Apr-15	16.63	17.63	16.6	18.1
18-Apr-15	16.63	19.64	16.6	20.11
19-Apr-15	14.63	17.13	14.6	17.1
20-Apr-15	13.12	15.13	13.09	15.6
21-Apr-15	12.62	13.62	12.59	13.6
22-Apr-15	12.12	16.13	12.09	16.1
23-Apr-15	13.62	17.63	13.6	18.1
24-Apr-15	15.13	17.13	15.1	17.6
25-Apr-15	13.12	15.63	13.09	16.1
26-Apr-15	12.62	16.13	12.59	16.1
27-Apr-15	10.62	16.13	10.59	16.1
28-Apr-15	11.12	16.63	11.09	16.6
29-Apr-15	10.62	15.63	10.59	15.6
30-Apr-15	12.12	15.13	12.09	15.1
1-May-15	12.62	15.13	12.59	15.6
2-May-15	13.62	16.63	13.6	17.1
3-May-15	13.62	18.13	13.6	18.1
4-May-15	13.12	18.13	13.09	18.1
5-May-15	12.62	16.63	12.59	17.1
6-May-15	11.62	15.13	11.59	15.6
7-May-15	11.12	14.63	11.09	15.1
8-May-15	10.62	15.13	10.59	15.1
9-May-15	10.62	14.13	10.59	14.1
10-May-15	11.62	14.13	11.59	14.6
11-May-15	11.12	14.63	11.09	15.1
12-May-15	11.62	14.13	11.59	14.6
13-May-15	9.61	12.12	9.58	12.59
14-May-15	7.6	12.62	7.58	12.59
15-May-15	8.11	13.12	8.08	13.09
16-May-15	9.11	13.62	9.08	13.6
17-May-15	8.11	13.12	8.08	13.09

Date	Zone 1b Daily Min (˚C)	Zone 1b Daily Max (˚C)	Zone 2b Daily Min (˚C)	Zone 2b Daily Max (˚C)
18-May-15	7.6	12.62	7.58	12.59
19-May-15	9.61	12.12	10.09	12.09
20-May-15	10.62	14.63	10.59	14.6
21-May-15	9.61	13.62	10.09	13.6
22-May-15	10.62	13.62	11.09	13.6
23-May-15	8.61	12.62	8.58	12.59
24-May-15	6.6	11.12	7.08	11.09
25-May-15	7.6	10.62	7.58	10.59
26-May-15	6.1	10.62	6.07	10.59
27-May-15	7.6	11.12	7.58	11.59
28-May-15	7.6	11.12	8.08	11.09
29-May-15	9.61	13.12	10.09	13.09
30-May-15	7.6	11.12	7.58	11.59
31-May-15	7.6	10.62	7.58	11.09
1-Jun-15	7.1	10.62	7.58	11.09
2-Jun-15	5.09	9.11	5.57	9.58
3-Jun-15	4.59	8.61	5.07	9.08
4-Jun-15	4.09	8.11	4.57	8.58
5-Jun-15	6.6	9.61	7.08	10.59
6-Jun-15	5.09	8.61	5.07	9.58
7-Jun-15	4.59	9.11	5.07	10.09
8-Jun-15	6.1	10.11	6.57	10.59
9-Jun-15	7.6	11.62	8.08	12.09
10-Jun-15	6.1	9.61	6.07	10.09
11-Jun-15	5.09	8.61	5.57	9.58
12-Jun-15	4.59	8.61	5.07	9.58
13-Jun-15	5.09	9.11	5.57	9.58
14-Jun-15	5.59	9.11	6.07	10.09
15-Jun-15	6.6	10.11	7.08	10.59
16-Jun-15	9.61	10.62	10.09	11.09
17-Jun-15	10.62	11.12	10.59	11.09
18-Jun-15	9.61	11.12	9.58	11.09
19-Jun-15	8.11	10.62	8.08	10.59
20-Jun-15	6.1	9.11	6.57	9.58
21-Jun-15	5.59	8.61	5.57	9.08
22-Jun-15	4.59	8.11	4.57	8.08
23-Jun-15	5.09	8.11	5.07	8.58
24-Jun-15	7.1	9.61	7.08	10.09
25-Jun-15	7.1	10.11	7.58	10.59
26-Jun-15	6.6	9.61	7.08	10.09
27-Jun-15	5.59	8.11	6.07	8.58
28-Jun-15	6.6	9.11	7.08	9.58
29-Jun-15	5.59	8.61	5.57	9.08
30-Jun-15	5.59	8.61	6.07	9.08

Date	Zone 1b Daily Min (˚C)	Zone 1b Daily Max (˚C)	Zone 2b Daily Min (˚C)	Zone 2b Daily Max (˚C)
1-Jul-15	5.09	7.6	5.57	8.58
2-Jul-15	4.59	7.1	5.07	7.58
3-Jul-15	3.08	6.1	3.56	7.08
4-Jul-15	3.59	6.1	3.56	6.57
5-Jul-15	3.59	5.59	3.56	6.07
6-Jul-15	5.09	7.6	5.07	8.08
7-Jul-15	4.09	7.6	4.06	7.58
8-Jul-15	4.59	8.11	5.07	8.58
9-Jul-15	5.09	8.61	5.57	9.08
10-Jul-15	5.59	7.6	6.07	7.58
11-Jul-15	6.6	9.11	7.08	9.08
12-Jul-15	6.6	8.11	7.08	8.58
13-Jul-15	6.6	9.11	6.57	9.58
14-Jul-15	6.6	9.11	6.57	9.58
15-Jul-15	6.1	8.11	6.57	8.08
16-Jul-15	5.59	8.61	5.57	8.58
17-Jul-15	6.1	9.11	6.57	9.08
18-Jul-15	5.09	8.61	5.07	8.58
19-Jul-15	4.09	8.61	4.06	8.58
20-Jul-15	4.09	8.61	4.06	8.08
21-Jul-15	4.09	8.61	4.06	8.58
22-Jul-15	5.59	7.6	5.57	7.58
23-Jul-15	7.1	9.11	7.08	9.08
24-Jul-15	7.1	9.11	7.08	9.58
25-Jul-15	7.6	9.61	7.58	9.58
26-Jul-15	7.1	9.61	7.08	10.09
27-Jul-15	5.09	9.11	5.57	9.08
28-Jul-15	4.59	9.11	4.57	9.08
29-Jul-15	5.09	9.61	5.07	9.08
30-Jul-15	5.09	9.11	5.07	9.08
31-Jul-15	6.1	10.62	6.07	10.09
1-Aug-15	7.1	10.11	7.08	10.09
2-Aug-15	7.6	10.62	8.08	11.09
3-Aug-15	7.1	10.11	7.08	10.09
4-Aug-15	4.59	9.11	4.57	9.08
5-Aug-15	5.09	8.61	5.57	9.08
6-Aug-15	4.59	9.11	5.07	9.58
7-Aug-15	5.09	9.61	5.57	9.58
8-Aug-15	5.59	10.11	5.57	10.09
9-Aug-15	4.59	9.61	5.07	9.58
10-Aug-15	6.6	10.62	6.57	10.59
11-Aug-15	6.6	11.12	6.57	11.09
12-Aug-15	5.59	7.6	5.57	7.58
13-Aug-15	5.09	10.11	5.07	10.09

Date	Zone 1b Daily Min (˚C)	Zone 1b Daily Max (˚C)	Zone 2b Daily Min (˚C)	Zone 2b Daily Max (˚C)
14-Aug-15	5.09	10.62	5.07	10.59
15-Aug-15	6.1	10.62	6.07	10.59
16-Aug-15	7.6	12.12	7.58	12.09
17-Aug-15	7.1	11.12	7.08	11.09
18-Aug-15	6.1	11.12	6.07	11.09
19-Aug-15	5.59	10.62	6.07	10.59
20-Aug-15	6.6	11.62	6.57	11.59
21-Aug-15	6.1	11.62	6.07	11.59
22-Aug-15	8.11	13.62	8.08	13.6
23-Aug-15	10.11	12.62	10.09	13.09
24-Aug-15	9.61	11.12	10.09	11.09
25-Aug-15	9.11	10.62	9.08	10.59
26-Aug-15	8.61	11.62	8.58	12.09
27-Aug-15	10.11	13.12	10.09	13.6
28-Aug-15	9.11	13.12	9.58	13.09
29-Aug-15	9.11	13.62	9.08	14.1
30-Aug-15	7.6	13.12	8.08	13.09
31-Aug-15	7.6	13.62	8.08	13.6
1-Sep-15	7.6	13.62	8.08	13.6
2-Sep-15	7.6	13.62	7.58	13.6
3-Sep-15	10.11	12.12	10.09	12.59
4-Sep-15	8.11	14.13	8.58	14.6
5-Sep-15	8.61	14.63	8.58	14.6
6-Sep-15	10.11	13.12	10.09	13.09
7-Sep-15	9.11	14.13	9.58	14.6
8-Sep-15	8.61	13.12	9.08	13.6
9-Sep-15	7.6	14.13	8.08	14.6
10-Sep-15	9.61	15.63	10.09	15.6
11-Sep-15	9.11	15.63	9.58	16.1
12-Sep-15	9.61	16.13	10.09	16.6
13-Sep-15	10.11	17.13	10.59	17.1
14-Sep-15	10.62	17.63	10.59	17.6
15-Sep-15	11.62	17.13	11.59	17.6
16-Sep-15	10.11	16.63	10.59	17.1
17-Sep-15	10.11	16.63	10.09	16.6
18-Sep-15	11.62	17.63	11.59	17.6
19-Sep-15	11.12	14.63	11.59	15.1
20-Sep-15	11.62	18.13	11.59	18.1
21-Sep-15	11.12	17.63	11.59	17.6
22-Sep-15	10.62	15.13	11.59	15.6
23-Sep-15	9.11	15.13	9.58	15.6
24-Sep-15	9.11	15.13	9.58	15.6
25-Sep-15	9.61	15.13	10.09	15.6
26-Sep-15	9.61	15.13	10.09	15.6

Date	Zone 1b Daily Min (˚C)	Zone 1b Daily Max (˚C)	Zone 2b Daily Min (˚C)	Zone 2b Daily Max (˚C)
27-Sep-15	10.62	18.13	10.59	18.61
28-Sep-15	11.62	19.13	11.59	19.61
29-Sep-15	11.62	19.13	12.09	20.11
30-Sep-15	11.62	19.64	12.09	20.11
1-Oct-15	14.63	21.64	15.1	22.11
2-Oct-15	13.12	21.64	13.09	22.11
3-Oct-15	13.62	22.14	13.6	22.61
4-Oct-15	14.13	21.14	14.6	21.61
5-Oct-15	15.13	23.14	15.6	24.11
6-Oct-15	15.13	24.14	15.6	24.61
7-Oct-15	15.63	19.13	16.1	19.61
8-Oct-15	14.63	20.64	15.6	21.11
9-Oct-15	15.13	23.64	15.6	24.61
10-Oct-15	15.63	23.64	16.1	24.11
11-Oct-15	15.13	19.64	15.6	20.61
12-Oct-15	15.13	23.64	16.1	25.11
13-Oct-15	16.63	21.14	17.6	22.11
14-Oct-15	16.63	24.14	17.1	24.61
15-Oct-15	16.63	25.64	17.1	26.61
16-Oct-15	16.63	26.14	17.6	27.61
17-Oct-15	18.63	23.64	19.61	24.11
18-Oct-15	17.63	22.14	18.61	23.11
19-Oct-15	17.63	26.14	18.61	27.11
20-Oct-15	18.13	26.64	18.61	28.11
21-Oct-15	19.64	22.64	20.11	23.61
22-Oct-15	18.13	21.14	18.61	22.11
23-Oct-15	16.63	20.14	17.1	21.61
24-Oct-15	15.63	22.64	16.6	24.11
25-Oct-15	15.13	24.14	15.6	26.11
26-Oct-15	16.63	23.64	17.6	25.11
27-Oct-15	17.13	24.64	18.1	26.61
28-Oct-15	16.63	25.64	18.1	27.11
29-Oct-15	16.63	26.14	17.6	27.61
30-Oct-15	17.63	25.64	18.61	27.61
31-Oct-15	17.63	21.64	18.61	22.61
1-Nov-15	16.63	21.64	17.6	22.61
2-Nov-15	17.63	23.64	18.1	25.11
3-Nov-15	18.63	21.64	19.11	23.11
4-Nov-15	18.13	19.64	18.61	20.61
5-Nov-15	17.13	19.13	18.1	20.11
6-Nov-15	17.63	22.64	18.1	24.11
7-Nov-15	17.63	24.64	18.1	26.61
8-Nov-15	18.63	23.64	19.11	25.11
9-Nov-15	18.13	25.14	18.61	26.61

Date	Zone 1b Daily Min (˚C)	Zone 1b Daily Max (˚C)	Zone 2b Daily Min (˚C)	Zone 2b Daily Max (˚C)
10-Nov-15	18.63	26.14	19.11	27.11
11-Nov-15	19.13	21.14	19.61	21.61
12-Nov-15	18.63	21.14	19.11	21.61
13-Nov-15	18.13	22.64	18.61	23.11
14-Nov-15	17.63	19.64	18.1	20.11
15-Nov-15	17.13	21.64	17.1	22.61
16-Nov-15	16.63	24.14	16.6	25.61
17-Nov-15	17.63	25.14	18.1	26.61
18-Nov-15	18.13	25.64	19.11	27.61
19-Nov-15	19.13	26.14	19.61	27.61
20-Nov-15	20.14	27.64	20.61	29.61
21-Nov-15	21.14	28.14	21.61	29.61
22-Nov-15	21.14	27.14	21.61	28.11
23-Nov-15	19.64	27.64	20.11	29.61
24-Nov-15	19.64	28.14	20.11	30.11
25-Nov-15	19.13	28.14	19.61	30.11
26-Nov-15	21.14	27.64	22.11	30.11
27-Nov-15	17.63	27.14	19.11	29.61
28-Nov-15	19.64	27.14	21.11	29.11
29-Nov-15	21.64	29.14	22.61	31.61
30-Nov-15	20.14	29.64	21.61	32.1
1-Dec-15	20.64	28.14	22.11	30.11
2-Dec-15	21.14	29.14	22.61	31.61
3-Dec-15	20.14	29.64	21.61	31.61
4-Dec-15	21.14	30.14	22.61	32.6
5-Dec-15	21.14	31.14	22.61	33.1
6-Dec-15	21.64	31.63	23.11	33.6
7-Dec-15	23.14	27.64	24.61	29.11
8-Dec-15	22.64	25.64	24.11	27.11
9-Dec-15	22.14	31.14	23.11	33.1
10-Dec-15	22.14	32.13	23.61	33.6
11-Dec-15	22.64	31.63	24.11	34.1
12-Dec-15	21.14	31.14	22.61	33.6
13-Dec-15	22.14	30.64	23.61	32.6
14-Dec-15	21.14	32.13	22.61	34.6
15-Dec-15	22.64	28.64	24.11	29.61
16-Dec-15	22.14	29.64	23.61	31.11
17-Dec-15	19.64	29.64	20.61	32.1
18-Dec-15	21.64	35.63	22.61	33.1
19-Dec-15	23.64	26.64	24.11	33.1
20-Dec-15	25.14	27.64	25.11	35.6
21-Dec-15	22.14	26.64	26.11	30.61
22-Dec-15	22.64	24.14	24.11	31.61
23-Dec-15	23.14	23.64	24.11	32.6

Date	Zone 1b Daily Min (˚C)	Zone 1b Daily Max (˚C)	Zone 2b Daily Min (˚C)	Zone 2b Daily Max (˚C)
24-Dec-15	22.14	23.64	22.11	30.61
25-Dec-15	22.64	24.14	22.11	32.1
26-Dec-15	23.14	24.14	22.61	24.61
27-Dec-15	23.14	24.14	20.11	29.11
28-Dec-15	22.64	23.64	19.61	29.11
29-Dec-15	22.14	23.14	20.61	31.11
30-Dec-15	21.64	23.14	21.61	32.6
31-Dec-15	21.64	23.14	22.61	33.6
1-Jan-16	23.14	25.14	24.61	34.1
2-Jan-16	24.64	25.64	24.11	28.61
3-Jan-16	24.64	25.64	22.11	28.61
4-Jan-16	23.64	24.64	21.61	24.11
5-Jan-16	23.14	24.14	20.11	22.61
6-Jan-16	22.64	24.14	20.11	23.11
7-Jan-16	22.14	23.64	18.1	26.11
8-Jan-16	22.64	24.14	19.11	29.11
9-Jan-16	23.14	24.64	21.61	30.61
10-Jan-16	24.14	26.14	22.61	32.6
11-Jan-16	22.64	25.64	23.61	32.1
12-Jan-16	22.64	24.64	24.11	32.6
13-Jan-16	22.64	25.14	24.11	34.6
14-Jan-16	23.14	25.14	25.11	30.61
15-Jan-16	22.64	24.14	21.61	29.11
16-Jan-16	22.64	24.14	20.61	28.61
17-Jan-16	23.14	24.64	21.11	31.61
18-Jan-16	23.14	24.64	23.11	33.6
19-Jan-16	23.14	24.64	24.11	34.6
20-Jan-16	23.64	25.14	25.11	31.11
21-Jan-16	23.64	25.14	24.61	31.11
22-Jan-16	23.64	24.64	24.11	26.61
23-Jan-16	23.64	25.14	22.61	29.61
24-Jan-16	24.14	25.64	23.11	29.11
25-Jan-16	23.14	24.64	23.11	27.61
26-Jan-16	23.64	25.14	22.61	29.11
27-Jan-16	22.64	24.14	22.61	25.61
28-Jan-16	23.64	24.64	21.61	30.11
29-Jan-16	23.64	24.64	22.61	25.11
30-Jan-16	23.14	24.64	20.11	26.61
31-Jan-16	23.14	24.14	20.11	25.61
1-Feb-16	22.64	23.64	20.11	24.11
2-Feb-16	22.64	24.14	22.11	24.61
3-Feb-16	23.14	23.64	23.11	23.61

APPENDIX E – SUMMARISED METEOROLOGICAL DATA 2013 - 2015

Year	Month	Monthly Precipitation (mm)	Average Maximum Daily Air Temperature (ºC)	Average Minimum Daily Air Temperature (ºC)	Average Maximum Daily Soil Temperature (ºC at 10 cm depth)	Average Minimum Daily Soil Temperature (ºC at 10 cm depth)
2013	January	72.6	32.3	13.9	33.2	23.8
2013	February	30	27.4	12.8	30.0	21.4
2013	March	197.2	25.7	9.6		
2013	April	9.8	22.1	5.5		
2013	May	19.8	17.4	1.3		
2013	June	85.2	13.9	1.6		
2013	July	42.8	13.4	1.7	10.5	6.2
2013	August	27	14.8	2.4	12.1	6.6
2013	September	91	19.9	4.0	17.8	10.8
2013	October	13.4	21.9	3.8	21.7	13.3
2013	November	105.6	23.8	6.7	25.3	16.3
2013	December	23.2	28.5	11.5	33.7	23.6
2014	January	4.8	31.6	12.1	35.7	24.8
2014	February	83.6	29.4	13.5	33.2	23.8
2014	March	88	24.2	12.2	25.0	18.7
2014	April	16.9	19.7	7.4	19.3	13.9
2014	May	14.4	17.6	2.7	14.7	9.5
2014	June	57.2	13.2	2.8	10.7	7.3
2014	July	34.9	12.2	0.0	9.1	4.9
2014	August	26.8	14.3	-0.8	11.8	5.7
2014	September	36.2	17.9	2.7	16.9	9.5
2014	October	53.4	22.5	5.4	22.5	13.9
2014	November	29	27.9	10.2	29.5	19.9
2014	December	102	27.7	12.7	29.5	20.4
2015	January	34.8	27.2	13.9	29.6	21.4
2015	February	30.2	28.3	13.0	30.0	21.4
2015	March	12.4	26.1	9.0	27.1	18.6
2015	April	91.8	19.1	7.1	17.7	12.6
2015	May	12.2	16.0	2.8	14.0	8.8
2015	June	55.2	13.7	-0.8	10.6	5.7
2015	July	37.2	11.6	-0.7	8.6	3.9
2015	August	66.8	13.7	1.0	10.7	5.3
2015	September	13.6	17.7	1.5	17.3	8.7
2015	October	26.6	24.8	8.3	24.6	16.2
2015	November	67.6	25.6	10.9	26.1	17.9
2015	December	34.8	29.3	11.4	32.3	21.9

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York Park Conservation Area
Prepared for 22 Barton Pty Ltd
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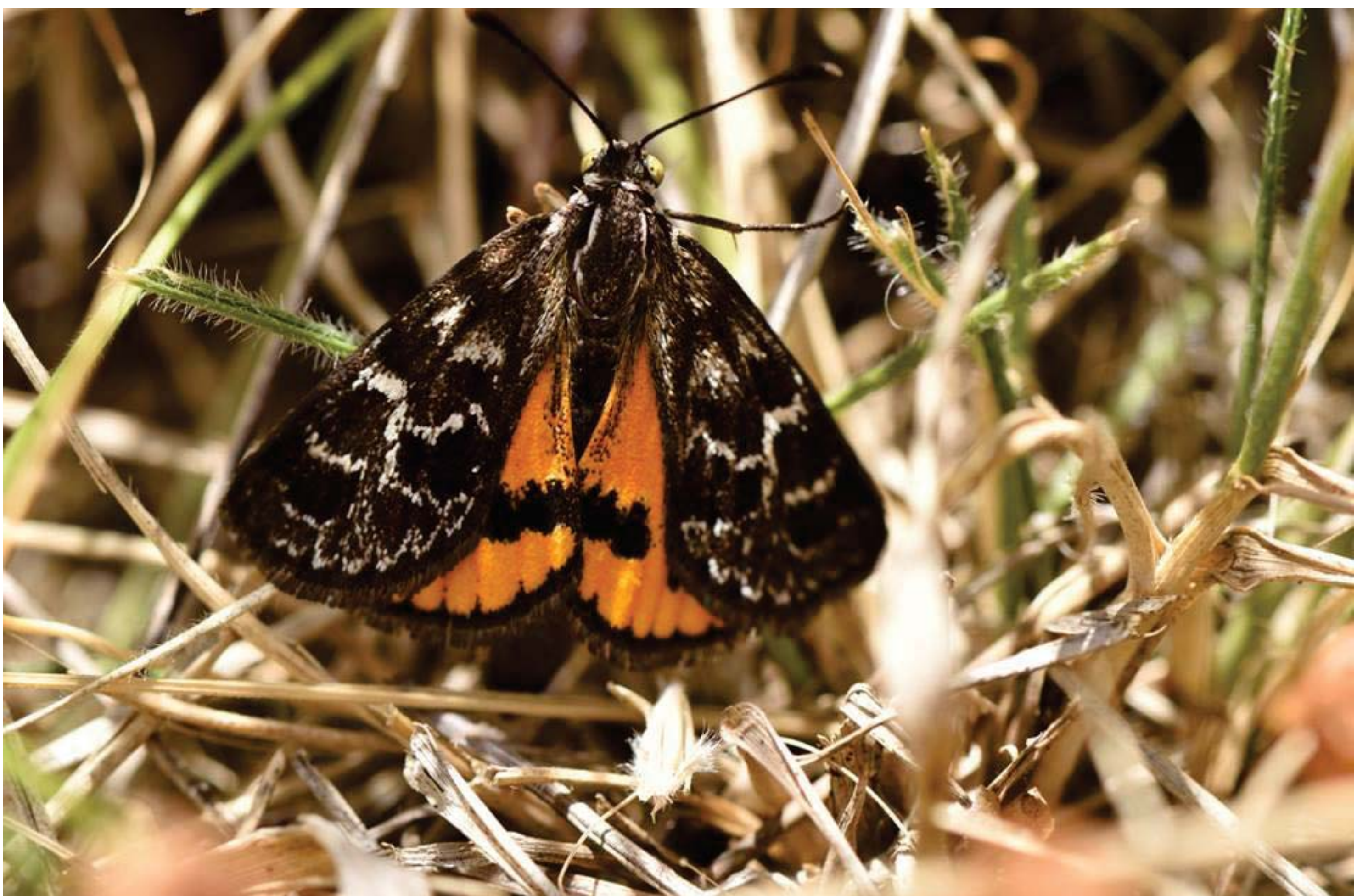
Canberra

Member of the Surbana Jurong Group

Golden Sun Moth Monitoring 2016

York Park Conservation Area

Prepared for: 22 Barton Pty Ltd
Reference No: 3002500
16/06/2017



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Executive Summary

Introduction

SMEC Australia Pty Ltd prepared this monitoring report on behalf of 22 Barton Pty Ltd to meet the annual reporting requirements of the *Potential shading impacts on York Park golden sun monitoring plan* (RJPL 2014a). This report presents the results of the year 4 golden sun moth (*Synemon plana,* GSM) flying moth survey, pupae case search and vegetation condition assessment conducted in 2016 in accordance with the monitoring plan.

Key Findings

The key results are:

- Flying GSM were recorded in low-moderate numbers during the 2016 season which is consistent with the past three years.
- Detection rates of GSM pupae cases at York Park remain low. Six pupae cases were found in 2016. Some emergence continues within the impact zone. This detection rate is too low to enable BACI analysis of pupae cases.
- Vegetation composition and condition throughout York Park was comparable to 2015. A slightly greater number of native and exotic species were recorded in 2016 than in 2015. Noxious weeds such as St John's Wort (*Hypericum perforatum*) were prevalent at York Park during 2016.
- Data from the loggers deployed at York Park during 2016/17 suggest that soil temperatures are approximately 1.0° C cooler in zone 1a than in zones 1b, 2a and 2b from June to August and up to 3.0° C warmer during January and February.
- Inferences about long-term trends in GSM abundance or vegetation condition in shaded and unshaded zones cannot be made based on the four years of monitoring data collected to date. One more year of monitoring is required to undertake an assessment of trends.

This report fulfils the reporting requirements for GSM monitoring at York Park for year 4, as specified in the monitoring plan (RJPL 2014a).

Recommendations

- On-going monitoring and control of weeds at York Park, particularly perennial exotic grasses and St John's Wort.
- The continuation of GSM flying moth and soil temperature monitoring during 2017.
- Commence discussions with DoEE to cease pupae case sampling in quadrats for BACI analysis. Continued monitoring of pupae case emergence in 2017 may, however, provide non-statistical information regarding the emergence of GSM from shaded areas.

1. Introduction

SMEC Australia Pty Ltd prepared this monitoring report, on behalf of Section 22 Barton Pty Ltd, to meet the 2017 annual reporting requirements of the *Potential shading impacts on York Park golden sun monitoring plan* (RJPL 2014a).

The monitoring plan was developed to meet Commonwealth *Environment Protection Biodiversity Conservation 1999 Act* (EPBC Act) approval decision (EPBC 2012/6606) conditions for development of a hotel and carpark at Block 14 Section 22 Barton (14/22 Barton). The monitoring plan contains a detailed description of the site, proposed actions and monitoring procedures (RJPL 2014a).

This report presents the findings of the year 4 monitoring survey undertaken during spring and summer 2016 for flying golden sun moth (*Synemon plana*) (GSM), pupae cases and vegetation condition at York Park.

Data from the first three years of monitoring are presented in the York Park Golden Sun Moth Monitoring 2013 survey report (RJPL 2014b), 2014 survey report (RJPL 2015), 2015 survey report (SMEC 2016) and, where relevant, have been referenced for comparison. Only limited analysis of the monitoring data is possible after the 4th year of data collection, and BACI analysis is not to be undertaken until after the 5th year of data collection (RJPL 2014a).

2. Methods

2.1. Regional GSM Observations

ACT researchers and consultants coordinate as an informal monitoring group and annually share information regarding the timing and location of GSM sightings, particularly in relation to the start of the GSM flying season, in the ACT region. As this communication was intermittent, a summary of GSM activity recorded throughout the region could not be produced.

2.2. Flying Moth Surveys

As specified in the monitoring plan (RJPL 2014a), flying GSM surveys were conducted in a manner consistent with the ACT Government (2010a) GSM survey guidelines and with the annual monitoring approach presented in Umwelt (*in prep*, final report not provided), as follows:

- Flying GSMs would be counted along two 100 m transects along the long axis of York Park (Figure 1) and recorded as number of GSM per 100 m transect.
- The transect survey would be undertaken three times approximately half an hour apart during each survey day.
- To compare baseline GSM activity levels with post-shading GSM activity levels, two sets of rotational point counts, involving 10 repeated, 30 second rotational counts, would be conducted at one site in the centre of the York Park GSM site between the transect surveys (Figure 1). All GSM seen in a radius of 25 m are to be recorded. Any individuals that re-crossed the observer's visual path were double counted. Averages were calculated from the ten rotations at each point to provide number of GSM per 30 second rotation. Data recorded using this approach is comparable with data collected by Umwelt (Australia) Pty Ltd for the year 1, year 2 and year 3 surveys (RJPL 2014b, RJPL 2015, SMEC 2016).
- To compare activity levels in the northern and southern ends of the York Park GSM site, two sets of rotational point counts, involving 10 repeated, 30 second rotational counts, would be conducted at two sites approximately one third and two thirds of the way along the centre line of York Park GSM site between the transect surveys (Figure *1*), i.e. approximately 25 m from each end. All GSM seen in a radius of 25 m are to be recorded. Any individuals that re-cross the observer's visual path would be double counted. Averages were calculated from the ten rotations at each point to provide a number of GSM per 30 second rotation.

The start of the GSM flying season was confirmed using known reference sites in the ACT, including York Park, and consultation with the ACT GSM monitoring group. In practice, suitable daily weather conditions determine repeat survey timings and shorter survey return times of no less than 3 days may be applied.

Other on-site weather data was recorded during all flying GSM field surveys to assist with interpreting the GSM survey results annually. The following data was recorded during flying moth surveys:

- wind speed and direction
- air temperature
- cloud cover.

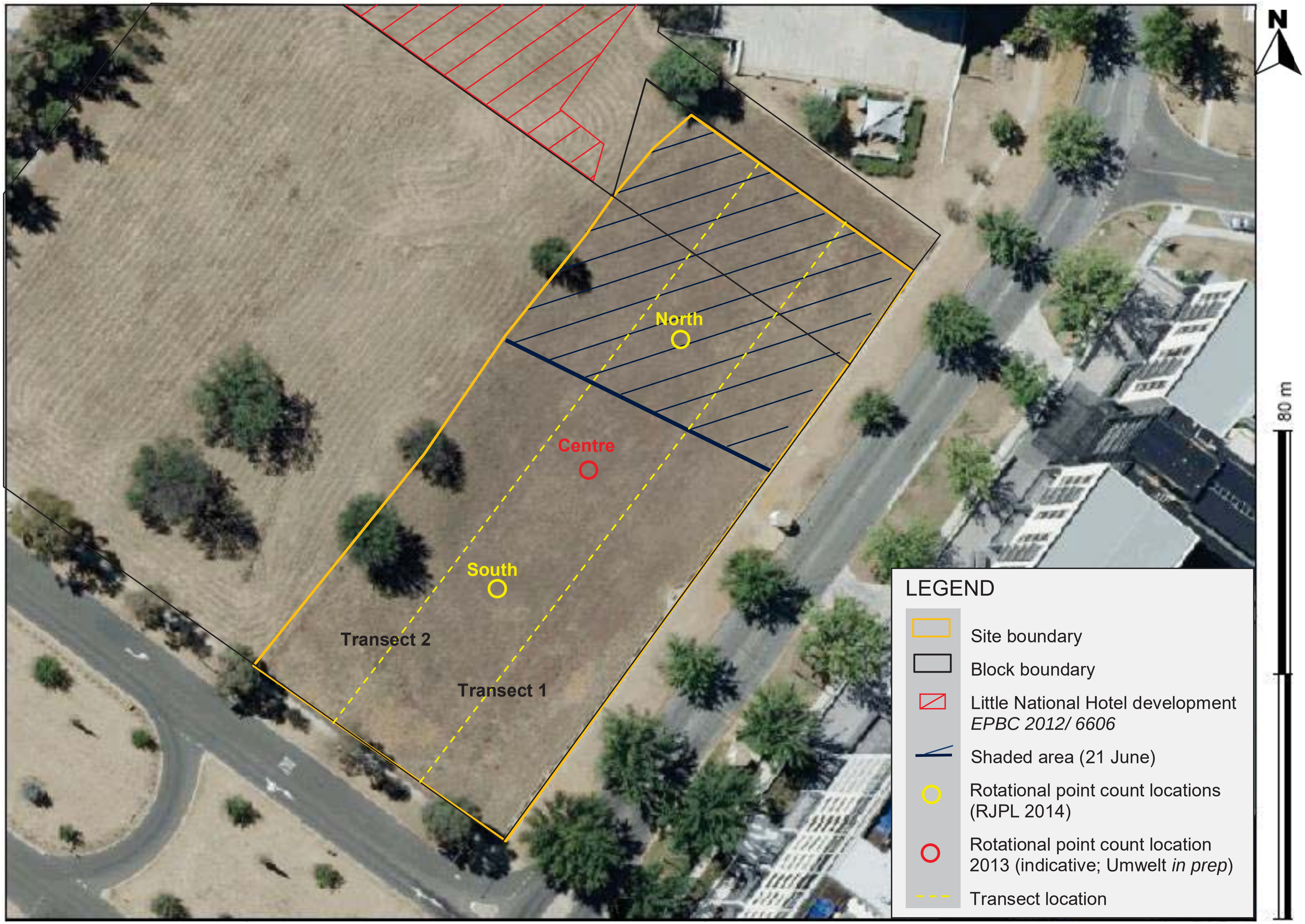

Figure 1. Location of flying GSM surveys at York Park.

2.3. Survey Area and Quadrat Placement

The survey area defined in the monitoring plan (RJPL 2014a) incorporates the York Park GSM site, and excludes the area now developed for road access to 14/22 Barton and areas of exotic perennial grasses and native *Poa* and *Themeda* plantings (Rowell 2012). As specified in the monitoring plan, the site is stratified into the following four zones for the pupae case surveys and vegetation assessments:

- Zone 1a: shaded by the development at 14/22 Barton (impact)
- Zone 1b: shaded by the development at 14/22 Barton and potentially shaded by the proposed development at Part 3/22 Barton (impact)
- Zone 2a: unshaded by the proposed development at 14/22 Barton and unshaded by the proposed development at Part 3/22 Barton (control)
- Zone 2b: unshaded by the proposed development at 14/22 Barton but potentially shaded by the proposed development at Part 3/22 Barton (control).

Twenty-four, 1 m^2 quadrats were established across the site at the beginning of the year 1 baseline survey season (RJPL 2014b). Each of these locations was approximately relocated using GPS locations and the map provided in the monitoring plan (RJPL 2014a). Plots were marked using wire pegs and plastic tags installed flush with the ground to permit relocation of the quadrats for repeat sampling during the season. All plot markers were removed at the end of the season. Figure 2 shows the York Park and GSM transect and plot locations and quadrat placement.

2.4. Pupae Case Monitoring

Pupae case surveys were conducted as specified in the monitoring plan (RJPL 2014a). Pupae cases were counted in each of the 24 quadrats approximately every two weeks over a six-week period (i.e. 3 times) during the GSM flying period from early-to-mid November until late December. All cases detected were removed for identification, also ensuring that individual pupa cases were not double counted.

2.5. Vegetation Monitoring

Data recorded for each quadrat included:

- all species present
- the dominant species (single or multiple)
- cover / abundance (%) using the Braun-Blanquet cover / abundance classes outlined in ACT Government (2010b).

Floristic value scores were calculated from abundance data based on Rehwinkel (2007) consistent with ACT Government (2010b).

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Figure 2. York Park GSM site pupal case and vegetation quadrat locations.

2.6. Soil Temperature Monitoring

On-site soil temperature monitoring in shaded and un-shaded areas commenced TidbiT v2 Temperature Loggers on 28 June 2016. Thermocron iButton temperature loggers previously installed had demonstrated a high failure rate and became unusable following a conflict with upgraded Thermocron software, and were consequently rreplaced. Temperature logger data was recovered on the 2 May 2017, and loggers were reinstalled.

2.7. Meteorological Data

Meteorological data from Canberra Airport was obtained for the period 2013 to 2016 to assist in the interpretation of potential shading impacts.

3. Results

3.1. Regional GSM Information

GSM were first observed flying during 2016 in the ACT on 16 November at Fisher Place, Ainslie and were flying at multiple sites (including York Park) by late November (A. Rowell, pers. comm.). The timing of the onset of the flying season is comparable with the 2015 season but commenced at least a week later than during the four seasons prior to 2015.

3.2. Flying Moth Surveys

Flying GSM were surveyed according to the method specified in the monitoring plan (RJPL 2014a) on three occasions during the GSM flying period. GSM survey dates and weather conditions are presented in Table *1*. All surveys were conducted whilst wind speeds were below 15 km/h and the air temperature was 30-34°C.

Table 1*. Site conditions during flying GSM surveys.*

Date	Max temperature (ºC)	Last rainfall (mm)	Wind peed (km/h)	Cloud cover (0-Nil, 8-Full)
18/11/2016	32.1	0.6 (15/11)	0–10	1/8
24/11/2016	31.0	4.2 (24/11)	0–10	8/8
9/12/2016	31.2	2.0 (9/12)	10-15	0/8

GSM were recorded in low-moderate numbers on both transects during each survey. GSM abundance was highest during the survey conducted on 24 November during which up to 26 GSM were observed on Transect 1 in comparison with six on 18 November and four on 12 December. A summary of the transect survey results and rotational point counts are presented in Table 2 and Table 3. Raw data from the 2016 flying moth surveys are presented in Appendix A.

Table 2. Summary of flying GSM numbers - Transect surveys.

Transect	Transect location	Average number of moths
Transect 1	East	9.1
Transect 2	West	5.7
Combined		7.4

Table 3. Summary of flying GSM numbers - Point count surveys.

Location	Average number of moths	Range
North East Point	2.8	0-12
Centre Point	3.0	0-11
South West Point	1.2	0-3

3.3. Pupae Case Surveys

Pupae case surveys were conducted per the method specified in the monitoring plan (RJPL 2014a) on three occasions. Surveys were undertaken on 24 November 2016, 9 December 2015 and 19 December 2016. Few pupae cases were recorded at York Park in 2016. No pupae cases were recorded in Zones 1a or 2b, whereas two were detected in Zone 1b and four were found in Zone 2a. Pupae case survey data are presented in Appendix B. A summary of the pupae case survey results for the control and impact zones is presented in Table 3. Summary of the pupae case surveys within control and impact sites.

Table 3. Summary of the pupae case surveys within control and impact sites.

Zone	Number of pupae cases	Average pupae cases per plot
Zone 1a	0	0
Zone 1b	2	0.7
Zone 1 (impact)	**2**	**0.2**
Zone 2a	4	0.4
Zone 2b	0	0
Zone 2 (control)	**4**	**0.3**

3.4. Vegetation Surveys

Dominant species, percentage cover and complete species lists, including Braun-Blanquet abundance scores, were recorded and calculated for each quadrat. A list of species presence / absence during 2016 is presented in Appendix 3 in relation to the overall York Park flora species list collated by Rowell (2012) and RJPL (2014a). A summary of the floristic value calculations for each quadrat is also presented in Appendix C. Table 4. Vegetation survey summary for the control and impact sites.

Table 4. Vegetation survey summary for the control and impact sites.

Zone	Floristic score		Native species	Exotic species	Cover (%)
	Average	Maximum	Average number		Average
Zone 1a	1.7	5	6.2	8.2	81.6
Zone 1b	4.3	7	8.0	5.6	80.0
Zone 1 (impact)	**3.0**	**7**	**7.1**	**6.9**	**81.2**
Zone 2a	2.3	11	4.7	8.0	75.0
Zone 2b	3.0	5	5.6	6.0	60.0
Zone 2 (control)	**2.6**	**11**	**5.2**	**7.0**	**72.5**

Figure 3. Location of pupae cases and vegetation quadrats with the highest floristic diversity.

3.5. Soil Temperature Monitoring

The four soil temperature loggers at York Park were retrieved on 2 May 2017 and data from the previous 11 months downloaded. Loggers were then redeployed in the same positions on 2 May 2017.

The daily maximum (i.e. at 3:00pm) and minimum (i.e. at 6:00am) temperatures recorded by the loggers are presented in Appendix D. Table 5 and Table 6 present the mean daily minimum temperature and mean daily maximum temperature respectively by month.

Table 5: Average daily minimum temperature recorded in zones 1a, 1b, 2a and 2b.

	1a (°C)	1b (°C)	2a (°C)	2b (°C)
Jun	6.5	7.3	7.8	7.7
Jul	6.2	7.1	7.4	7.4
Aug	7.0	7.6	7.8	7.9
Sep	10.9	11.0	11.2	11.4
Oct	13.0	12.7	13.1	13.6
Nov	18.8	17.8	18.3	18.7
Dec	22.6	21.5	21.9	22.3
Jan	25.8	24.6	24.9	25.3
Feb	23.8	22.8	23.1	23.6
Mar	20.7	20.3	20.5	20.8
Apr	14.3	14.3	14.4	14.7
Av.	15.4	15.2	15.5	15.8

Table 6. Average daily maximum temperature recorded in zones 1a, 1b, 2a and 2b.

	1a (°C)	1b (°C)	2a (°C)	2b (°C)
Jun	9.5	10.1	10.7	10.5
Jul	10.0	10.7	10.9	10.7
Aug	12.3	12.6	12.5	12.4
Sep	16.6	15.8	15.9	15.9
Oct	21.0	19.6	19.8	20.1
Nov	29.2	26.9	27.1	27.2
Dec	32.1	30.0	29.9	30.2
Jan	36.9	34.4	33.5	33.8

	1a (ºC)	1b (ºC)	2a (ºC)	2b (ºC)
Feb	34.1	32.2	31.3	31.9
Mar	27.5	26.5	26.0	26.7
Apr	19.2	19.0	19.0	19.5
Av.	**22.6**	**21.6**	**21.5**	**21.7**

3.6. **Meteorological Data**

Monthly rainfall and average daily maximum and minimum air temperatures recorded at Canberra Airport from 2013 to 2016 are presented in Figure *4*. Rainfall during the months leading up to the flying moth season was much greater in 2016 than during the previous three years. Figure 5 shows the monthly average daily maximum and minimum soil temperatures, recorded at 10 cm depth, from 2013 to 2016 at the Canberra Airport. Figure 6 shows daily maximum soil temperature and daily precipitation during the past four GSM flying seasons (i.e. October to December). During the 2016 flying period, soil temperatures at Canberra Airport were similar to previous years. There were no days during the 2016 flying period on which more than 25 mm of rain were recorded, unlike 2013 and 2014 when there were three and one respectively.

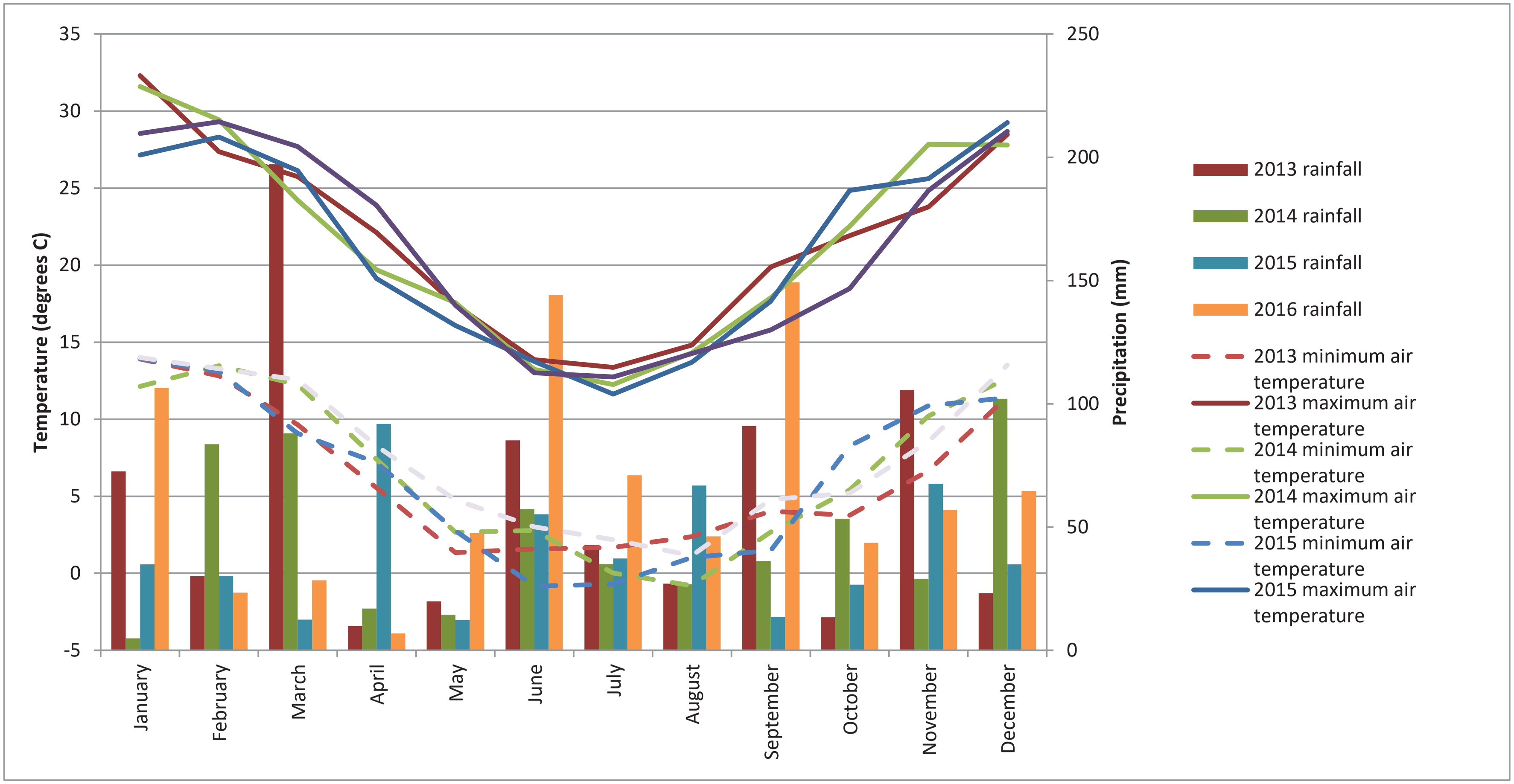

Figure 4. Monthly rainfall and average daily maximum and minimum air temperature at Canberra Airport.

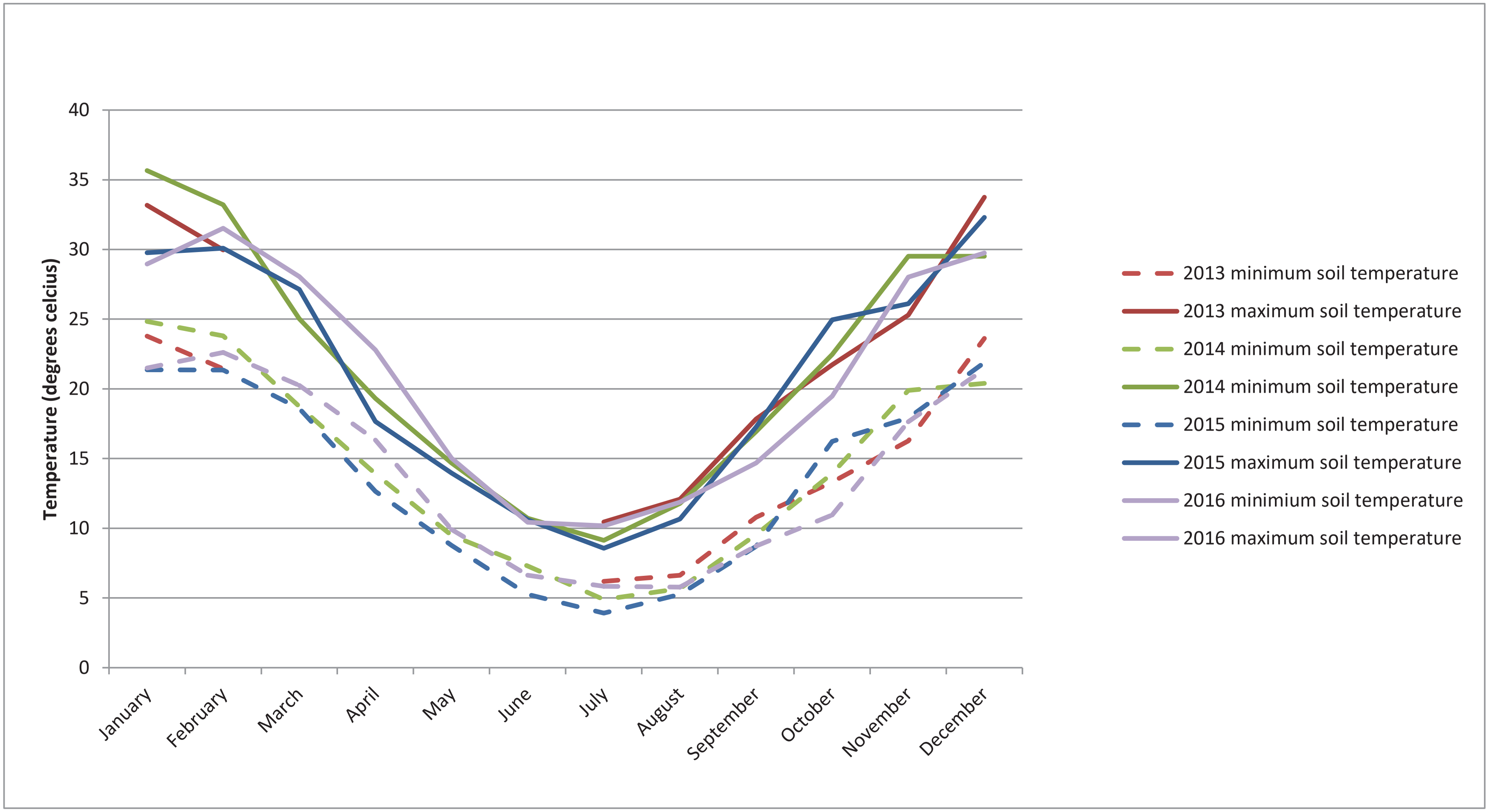

Figure 5. Monthly average daily maximum and minimum soil temperature (at 10 cm depth) at Canberra Airport.

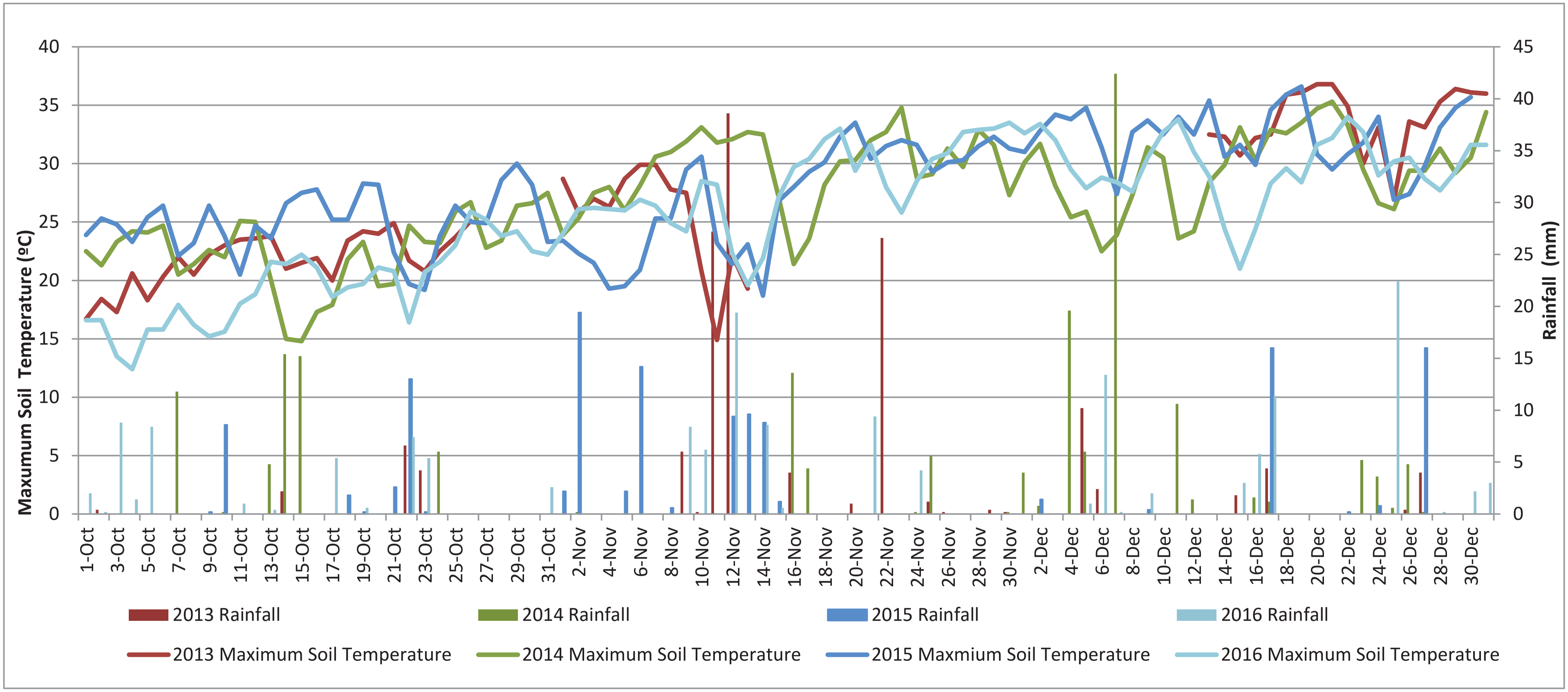

Figure 6. Maximum daily soil temperature and daily rainfall at Canberra Airport during the GSM flying period.

4. Discussion

4.1.1. Flying Moth Surveys

All flying moth surveys were undertaken during the peak period of GSM activity in the ACT and are therefore valid representations of GSM activity levels at the York Park GSM site.

Flying moth numbers observed were consistently low to moderate during the surveys according to the semi-quantitative GSM site assessment method developed by David Hogg Pty Ltd (2010). Flying moth numbers recorded during the 2016 flying season were comparable with 2015 (SMEC 2016), lower than 2014 and far higher than recorded in 2013 (RJPL 2014b) (Figure 7). Fewer moths were recorded for both transects in 2016 than during the previous two years, but a greater number of moths were recorded compared to 2013. Slightly fewer moths were recorded during 2016 (i.e. av. 1.2) at the south-west point than in 2015 (i.e. av. 2.0) though moth numbers observed at the north-east point and centre point were higher in 2016 than in the previous year.

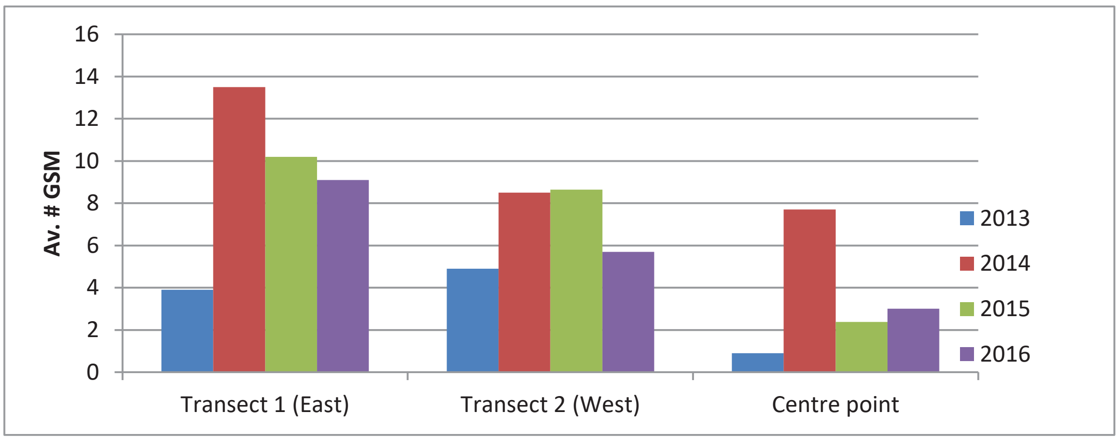

Figure 7. Average number of GSM observed on transect and centre point surveys from 2013 to 2016.

Previous studies conducted by Rowell (2012) and Richter *et al*. (2013a) at York Park found little variation in GSM densities over time. The variation observed in the last four years of monitoring observed has consistently remained in the low to moderate activity range. As the surveys were conducted at similar points during the flying season and weather conditions on survey days were generally comparable, it is likely that variation in moth numbers is due to climatic variation between years.

4.1.2. Pupae Case Surveys

Six pupae cases were detected during the 2016 search (i.e. two in the impact zone, four in the control zone) compared with six pupae cases recorded in 2015, five in 2014 and two in 2013. The proportion of pupae cases detected in the control plots relative to the impact plots were greater relative to previous years, however the number of pupae cases detected in the impact zone was within the range of detections in previous years. Mariation in pupae case detection between years, and between the control and impact sites, is potentially due to stochastic variation, given the low levels of detection. The low levels of detection persist despite the relatively high survey effort applied relative to the recommendations of Richter *et.al.* (2013b).

These very low pupae case numbers are indicative of the low density of GSM at York Park and the challenges associated with detecting pupae cases in low density areas. No change is evident relative to the baseline data regarding variation in breeding success between the control and impact zones.

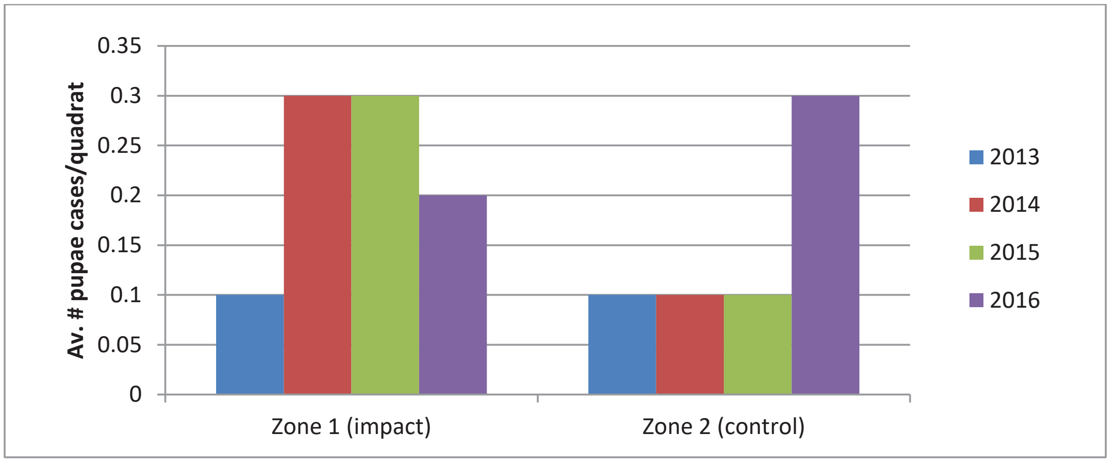

Figure 8. Average number of pupae cases recorded by quadrat in the control and impact zones.

4.1.3. Vegetation Surveys

Sites in the impact zone had marginally higher native and exotic species diversity compared to the control zone. No difference was recorded between vegetation cover for the impact and control zones. Floristic scores in 2016 were highest on average in zone 1b (i.e. 4.3) and lowest in zone 1a (i.e. 1.7). Floristic scores in zones 2a and 2b were 2.3 and 3 respectively. Native species diversity in the impact zone was higher in 2016 than in 2015 (Figure 9); however, the exotic species diversity in the impact zone also increased somewhat since the 2015 survey. Increases in the number of native and exotic species were also recorded in the control zone ().

The methodology to calculate the floristic value scores which underpin the classification of native grassland quality was revised in 2015 (Rehwinkel 2015). To allow comparisons with previous years, however, the 1 x1 m quadrats were assessed using the previous floristic value score method shown in Figure 9 and Figure 10. Vegetation in five quadrats in the impact zone had a floristic score of ≥4. This is higher than recorded in 2015. Five quadrats in the control zones had a floristic score of ≥4 or more, which is higher than 2015 records. It suggests using the previous method that the site consists of degraded natural temperate grassland, although scores are likely to be substantially higher if calculated for a 20 x 20 m plot as specified

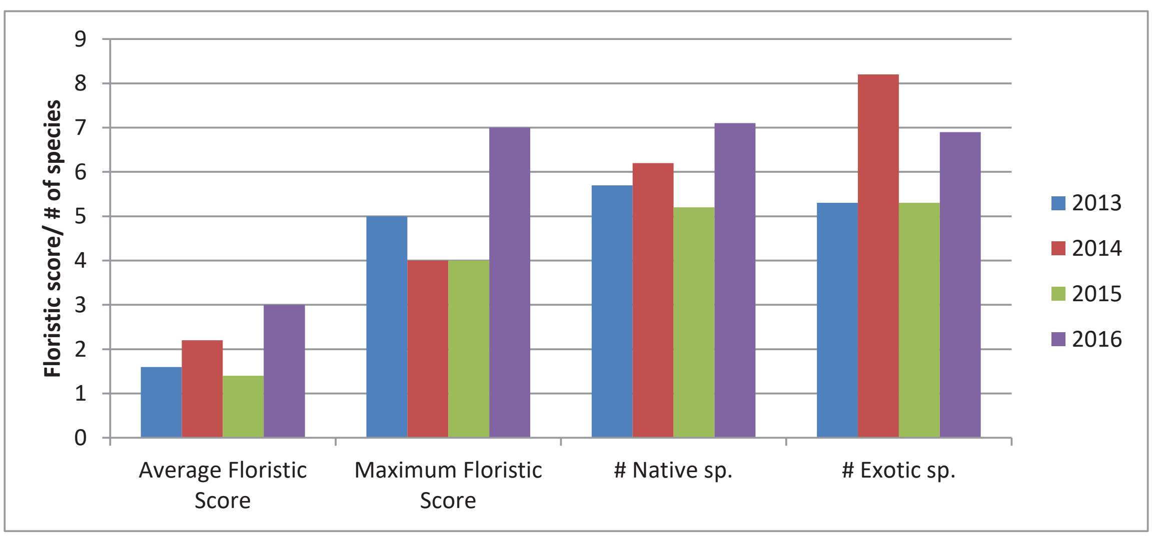

Figure 9. Comparison of impact zone vegetation statistics from 2013 to 2016.

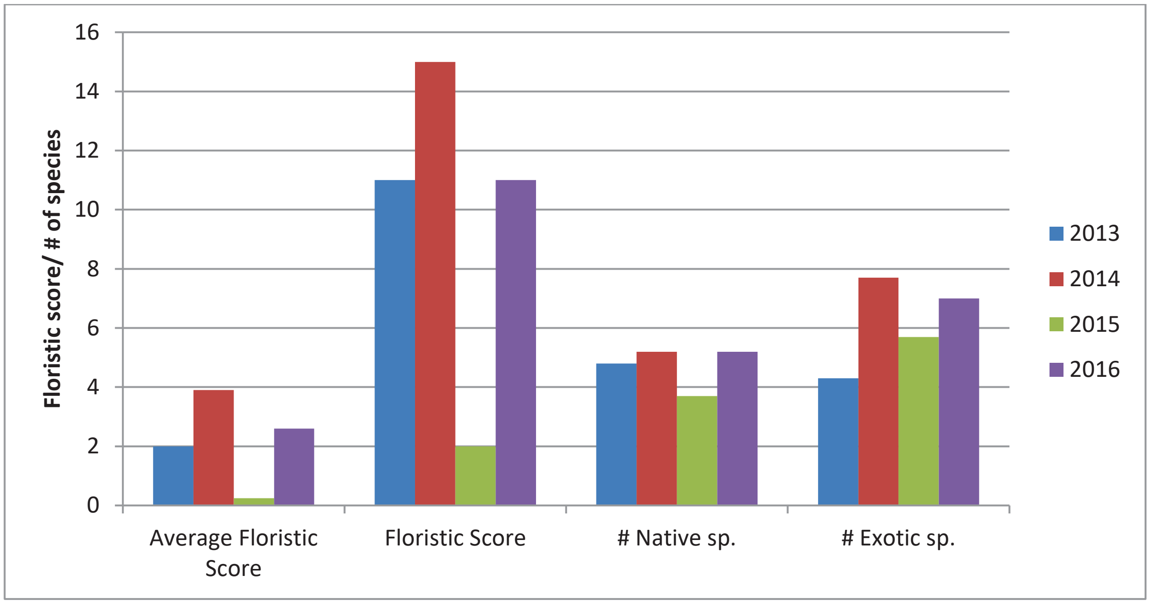

Figure 10. Comparison of control zone vegetation statistics by year.

The higher diversity and floristic scores recorded in 2016 relative to 2015 is likely due to climate variability; 2015 was substantially drier season compared to a wetter season in 2016. Floristic scores for 2016 are similar to those recorded in 2013 and 2014. The variation in vegetation composition may have occurred as the quadrats are not permanently marked out and as a consequently quadrats may be placed in slightly different positions each year.

4.2. Soil Temperature

Soil temperature readings from loggers located in zones 1b, 2a and 2b were relatively similar to each other year round; however, minimum and maximum temperatures recorded in zone 1a were considerably different to the other three sites during the winter and summer months.This is indicative of a potential shading effect on winter soil temperatures. The difference in soil temperature during the winter shading period between site 1a and 1b may partly be confounded by slightly different depths of deployed loggers.

During the months in which the sun angle in Canberra is at its lowest, (i.e. June, July) the mean minimum and maximum temperatures in zone 1a were 6.5 °C and 9.5 °C respectively in June and 6.2 °C and 10.0 °C respectively in July. In comparison, mean minimum and maximum temperatures were on average 7.6 °C and 10.4 °C respectively in June and 7.3 °C and 10.8 °C respectively during July across the unshaded section of York Park (i.e. zones 1b, 2a, 2b). Comparative mean temperatures recorded during 2014 were 8.7 °C and 11.0 °C (June) and 6.5 °C and 9.3 °C (July) across the unshaded area. Unfortunately no data was collected in zone 1a during 2014 or 2015 due to data logger malfunction.

During the peak summer months in 2017, average maximum temperatures were 1.5 - 3.5 °C greater at the site located in zone 1a than the other three sites. During January and February for example, the mean maximum temperature recorded in zone 1a was 36.9°C and 34.1°C respectively. The average maximum temperatures at the three other sites ranged between 33.5°C and 34.4°C in January and 31.3°C to 32.2°C in February (Table 6).

4.2.1. Climatic Conditions

The winter and spring months leading up to the flying moth season were far wetter in 2016 than during the past three years. The four months from July to September were the wettest such period on record in Canberra (Australian Government 2017), which may partly explain the delayed onset of the 2016 flying season. This wet period was followed by average rainfall from October to December (Australian Government 2017). The mean temperature in spring 2016 were consistent to previous years whilst the mean maximum temperature during September and October was the lowest in over a decade (Australian Government 2017). Soil temperatures in 2016 at Canberra Airport leading up to the GSM flying season were similar to previous surveys (i.e. 2013 to 2015). Minimum and maximum soil temperatures recorded at Canberra Airport during the months leading up to GSM emergence GSM (i.e. during September-October) were lower in 2016 than in the previous three years.

5. Compliance with the GSM Monitoring Plan

5.1. Survey Requirements

Transect surveys, pupae case surveys and vegetation surveys were conducted according to the methods specified in the monitoring plan (RJPL 2014a) and data from soil temperature loggers were successfully recovered and assessed. The maximum and minimum temperatures were determined from temperatures recorded at three hour intervals.

5.2. Reporting Requirements

The GSM monitoring plan (RJPL 2014a) requires that annual monitoring reports meet the following specifications:

- Annual monitoring and compliance reports would be prepared in a timely manner each year meeting the EPBC Act approval requirements (Conditions 3, 8) by:
    - providing and assessing the monitoring data for the previous twelve months against the baseline conditions
    - concluding whether or not there has been a decline in the GSM population in the area of York Park shaded as a result of the action, taking into account regional population trends and local ecological conditions
    - reviewing the GSMMP's applicability in achieving its objectives (Condition 8) to determine whether, under EPBC Act Approval Condition 10, the GSMMP should be revised in consultation with the Commonwealth.
- When preparing the report, reference would be made to the current NTGMP and any relevant management and monitoring changes relevant to a review of this GSMMP.

The current report represents the fourth baseline data monitoring report. The above requirements for analysis against the baseline conditions and assessment of whether there has been a decline in the population of GSM at York Park can only be qualitatively assessed at this stage.

The preparation of this report fulfils the reporting requirements for year 4 baseline surveys as specified in the monitoring plan (RJPL 2014a).

5.3. GSM Monitoring Plan Review

Monitoring of flying moth numbers and vegetation condition is progressing according to the GSM monitoring plan, and the data collected is appropriate for the analyses proposed. The current monitoring results suggest that the effectiveness of pupae case surveys and ongoing soil temperature monitoring may be limited, and requires reconsideration in consultation with DoE. These issues and the proposed responses are summarised in Table 5-1.

Pupae cases have consistently been detected at very low rates in the quadrats, despite the substantially higher survey effort implemented relative to the recommendations of Richter *et. al.* (2013). The very low detection rate is such that it is highly unlikely that any trends in pupae case numbers will be detected, and no meaningful BACI analysis of changes in pupae case numbers can be applied. Due to the uninformative nature of this data, the BACI analysis of pupae case numbers proposed in the GSM monitoring plan is not feasible. On this basiswe recommend that discussions with DoEE be commenced to discuss the discontinuation of pupae case sampling and that monitoring focuses on flying GSM and the comparison of vegetation condition in the control and impact zones. Continued monitoring of pupae case emergence, however, may provide non-statistical information regarding the emergence of GSM from shaded areas.

While there have been technical difficulties with soil temperature monitoring, preliminary results indicate that there may be a difference in soil temperature during the shading period between the control and impact areas. We recommend that this be confirmed through one more complete season of monitoring, and, if verified soil temperature monitoring can then be discontinued.

Table 5-1. Recommended changes to the GSM monitoring plan.

	Issue	Proposed response
Pupae Case Counts	The detection rate of moth pupae cases is insufficient for comparison of trends in shaded or non-shaded areas	Commence discussions with DoEE to end pupae case sampling in quadrats for BACI analysis. Monitoring should focus on general trends in flying GSM numbers across York Park and a comparison of vegetation condition in the control and impact zones. Continued monitoring of pupae case emergence may, however, provide non-statistical information regarding the emergence of GSM from shaded areas.
Soil Temperature Monitoring	Lack of continuous year-round soil temperature data prior to 2016/17.	Continue soil temperature monitoring for one more complete season. If there is no substantial difference (i.e. >1˚C) between impact and control zone soil temperatures during the winter shading period after one more complete monitoring period, we recommend that the soil temperature monitoring component be discontinued.

SMEC recommends that discussions with DoE be held during winter 2017 (prior to the GSM flying season) to determine the best approach to the issues identified in Table 5-1, and to reach agreement on any amendments to the GSM monitoring plan.

6. Conclusion

This report provides baseline results of flying GSM surveys, pupae case surveys and vegetation surveys for 2016 in accordance with the *Potential shading impacts on York Park golden sun monitoring plan* (RJPL 2014a, the monitoring plan). Surveys were conducted in a manner consistent with the survey requirements outlined in the monitoring plan (RJPL 2014a).

The surveys indicated that GSMs persist in low to moderate numbers at York Park and highlighted that pupae case detection rates are too low for analysis of differences in abundance between years or sites. The vegetation present at York Park is classified as degraded natural temperate grassland, though the majority of which is potential GSM breeding habitat.Flying moth abundance remains within the range of that detected in previous surveys.

Vegetation condition was generally consistent between the control and impact zones although variation between quadrats was apparent. The shading of zone 1a from 2015 onwards appears to have reduced soil temperatures during June and July in this area however further soil temperature monitoring is required to examine this properly.

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Appendices

Appendix A Flying GSM Survey 2016 – Transect Data

Date	Transect	Moth numbers / Survey time			Moth numbers
		1130	1200	1230	Average (1dp)
18/11/2016	Transect 1	6	3	1	3.3
28/11/2016	Transect 1	21	26	19	22.0
12/12/2016	Transect 1	4	2	0	2.0
18/11/2016	Transect 2	4	2	1	2.3
28/11/2016	Transect 2	10	19	8	12.3
12/12/2016	Transect 2	4	2	1	2.3

Appendix B Flying GSM Survey 2016 – Point Observations

Date	Time	Point	Moth numbers	
			Average (1dp)	Range
18/11/2016	12:20	North	0.9	0-3
28/11/2016	12:20	North	7.3	4-12
12/12/2016	13:50	North	0.1	0-1
18/11/2016	12:39	Centre	0.7	0-2
28/11/2016	12:31	Centre	8.3	4-10
12/12/2016	13:35	Centre	0.5	0-1
18/11/2016	13:26	Centre	0.2	0-2
28/11/2016	12:52	Centre	8.0	5-11
12/12/2016	14:10	Centre	0.2	0-1
18/11/2016	12:48	South	0.2	0-1
28/11/2016	12:30	South	1.7	0-3
12/12/2016	14:10	South	1.7	0-3

Appendix C Pupae Case Survey 2016

Date	Survey	Quadrat	Control or Impact site	Zone	Pupae case numbers	Notes
24/11/2016	1	1	Impact	1a	0	
24/11/2016	1	2	Impact	1a	0	
24/11/2016	1	3	Impact	1a	0	
24/11/2016	1	4	Impact	1a	0	
24/11/2016	1	5	Impact	1a	0	
24/11/2016	1	6	Impact	1a	0	
24/11/2016	1	7	Impact	1a	0	
24/11/2016	1	8	Impact	1a	0	
24/11/2016	1	9	Impact	1a	0	
24/11/2016	1	10	Impact	1b	0	
24/11/2016	1	11	Impact	1b	0	
24/11/2016	1	12	Impact	1b	0	
24/11/2016	1	13	Control	2b	0	
24/11/2016	1	14	Control	2b	0	
24/11/2016	1	15	Control	2a	0	
24/11/2016	1	16	Control	2a	**1**	*Delma impar* found
24/11/2016	1	17	Control	2a	0	
24/11/2016	1	18	Control	2a	0	
24/11/2016	1	19	Control	2a	0	
24/11/2016	1	20	Control	2b	0	
24/11/2016	1	21	Control	2a	0	
24/11/2016	1	22	Control	2a	0	
24/11/2016	1	23	Control	2a	0	
24/11/2016	1	24	Control	2a	0	
09/12/2016	2	1	Impact	1a	0	
09/12/2016	2	2	Impact	1a	0	
09/12/2016	2	3	Impact	1a	0	
09/12/2016	2	4	Impact	1a	0	
09/12/2016	2	5	Impact	1a	0	
09/12/2016	2	6	Impact	1a	0	
09/12/2016	2	7	Impact	1a	0	
09/12/2016	2	8	Impact	1a	0	
09/12/2016	2	9	Impact	1a	0	
09/12/2016	2	10	Impact	1b	**1**	
09/12/2016	2	11	Impact	1b	**1**	
09/12/2016	2	12	Impact	1b	0	
09/12/2016	2	13	Control	2b	0	
09/12/2016	2	14	Control	2b	0	
09/12/2016	2	15	Control	2a	0	
09/12/2016	2	16	Control	2a	0	
09/12/2016	2	17	Control	2a	**1**	

09/12/2016	2	18	Control	2a	**1**	
09/12/2016	2	19	Control	2a	0	
09/12/2016	2	20	Control	2b	0	
09/12/2016	2	21	Control	2a	0	
09/12/2016	2	22	Control	2a	0	
09/12/2016	2	23	Control	2a	0	
09/12/2016	2	24	Control	2a	0	
19/12/2016	3	1	Impact	1a	0	
19/12/2016	3	2	Impact	1a	0	
19/12/2016	3	3	Impact	1a	0	
19/12/2016	3	4	Impact	1a	0	
19/12/2016	3	5	Impact	1a	0	
19/12/2016	3	6	Impact	1a	0	
19/12/2016	3	7	Impact	1a	0	
19/12/2016	3	8	Impact	1a	0	
19/12/2016	3	9	Impact	1a	0	
19/12/2016	3	10	Impact	1b	0	
19/12/2016	3	11	Impact	1b	0	
19/12/2016	3	12	Impact	1b	0	
19/12/2016	3	13	Control	2b	0	
19/12/2016	3	14	Control	2b	0	
19/12/2016	3	15	Control	2a	0	
19/12/2016	3	16	Control	2a	0	
19/12/2016	3	17	Control	2a	0	
19/12/2016	3	18	Control	2a	0	
19/12/2016	3	19	Control	2a	0	
19/12/2016	3	20	Control	2b	0	
19/12/2016	3	21	Control	2a	0	
19/12/2016	3	22	Control	2a	**1**	Two male GSM flying across the plot
19/12/2016	3	23	Control	2a	0	
19/12/2016	3	24	Control	2a	0	

Appendix D Vegetation Survey 2016 – Dominant Species Per Quadrat

Date	Quadrat	Control or Impact site	Zone	Dominant	Co-Dominant	Cover (%)
18/11/2016	1	Impact	1a	*Dactylis glomerata**	*Paspalum dilatatum**	80
18/11/2016	2	Impact	1a	*Austrostipa bigeniculata*		70
18/11/2016	3	Impact	1a	*Austrostipa bigeniculata*	*Bothriochloa macra*	95
18/11/2016	4	Impact	1a	*Bothriochloa macra*	*Austrostipa bigeniculata*	90
18/11/2016	5	Impact	1a	*Austrostipa bigeniculata*		60
18/11/2016	6	Impact	1a	*Austrostipa bigeniculata*	*Hypochaeris radicata**	80
18/11/2016	7	Impact	1a	*Austrostipa bigeniculata*	*Bothriochloa macra*	90
18/11/2016	8	Impact	1a	*Bothriochloa macra*		80
18/11/2016	9	Impact	1a	*Bothriochloa macra*	*Panicum effusum**	90
18/11/2016	10	Impact	1b	*Austrostipa bigeniculata*	*Bothriochloa macra*	90
18/11/2016	11	Impact	1b	*Austrostipa bigeniculata*	*Dactylis glomerata**	70
18/11/2016	12	Impact	1b	*Austrostipa bigeniculata*		80
18/11/2016	13	Control	2b	*Austrostipa bigeniculata*		60
18/11/2016	14	Control	2b	*Bothriochloa macra*		60
18/11/2016	15	Control	2a	*Austrostipa bigeniculata*	*Bothriochloa macra*	90
18/11/2016	16	Control	2a	*Bothriochloa macra*		70
18/11/2016	17	Control	2a	*Bothriochloa macra*	*Austrostipa bigeniculata*	70
18/11/2016	18	Control	2a	*Bothriochloa macra*	*Themeda australis*	90
18/11/2016	19	Control	2a	*Austrostipa bigeniculata*	*Bothriochloa macra*	90
18/11/2016	20	Control	2b	*Austrostipa bigeniculata*	*Bothriochloa macra*	90
18/11/2016	21	Control	2a	*Austrostipa bigeniculata*		80
18/11/2016	22	Control	2a	*Bothriochloa macra*	*Austrostipa bigeniculata*	90
18/11/2016	23	Control	2a	*Dactylis glomerata**		40
18/11/2016	24	Control	2a	*Hypochaeris radicata**	*Vulpia* sp.*	40

Appendix E Vegetation Survey 2016 – Plant Species List

Scientific name	Common name	Quadrat number																							
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Native grasses																									
Aristida ramosa	Wiregrass					r	r																		
Austrodanthonia auriculata	Lobed Wallaby Grass																								
Austrodanthonia bipartita	A Wallaby Grass																								
Austrodanthonia caespitosa	Ringed Wallaby Grass								r	2							r		2	r					
Austrodanthonia carphoides	Short Wallaby Grass					+											2								
Austrodanthonia fulva	A Wallaby Grass																								
Austrodanthonia laevis	Smooth Wallaby Grass																								
Austrodanthonia spp.	Wallaby Grasses	r	r			r	r					2		r	2	2	2	2	2	2	1	1	2		
Austrostipa bigeniculata	Tall Speargrass	1	4	4	3	4	3	4	2	2	4	3	5	5	3	5		3	2	5	5		3	2	
Austrostipa densiflora	A Speargrass																								
Austrostipa scabra	Rough Speargrass					2					2									r					
Bothriochloa macra	Redleg Grass		1	2	3	1		2	4	4	3	4	2	3	5	3	5	4	3	5	3	2	5		
Chloris truncata	Windmill Grass																								
Elymus scaber	Wheatgrass																								
Eragrostis brownii	A Lovegrass																								
Eragrostis trachycarpa	A Lovegrass																								
Microlaena stipoides	Weeping Grass																								
Panicum effusum	Hairy Panic Grass	+		1			1		r	3		2	2	2	2		1	2		5	2	2	2		
Poa labillardieri	Tussock Grass																								
Themeda triandra	Kangaroo Grass	r																							
Native forbs																									
Acaena ovina	Sheeps Burr																								
Asperula conferta[2]	Common Woodruff																								
Bulbine bulbosa[2]	Golden Lily																								
Calocephalus citreus[2]	Lemon Beauty Heads																				+				
Carex sp.	Carex	1																							

Scientific name	Common name	Quadrat number																							
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Chamaesyce drummondii	Caustic Weed																								
Cheilanthes sp.[2]					r	+	+				+	+			+	+									
Cheilanthes sieberi[2]	Rock Fern																								
Cheilanthes tenuifolia[2]																									
Chenopodium pumilio	Small Crumbweed																								
Chrysocephalum apiculatum[1]	Yellow Buttons	+		2		1	2				1	1	1		+	1							1		
Chrysocephalum semipapposum	Clustered Everlasting																								
Convolvulus angustissimus	Australian Bindweed							r		r															
Crassula sieberiana	Australian Stonecrop																								
Cymbonotus lawsonianus	Bear's Ears																								
Drosera peltata	Sundew																								
Eryngium rostratum[2]	Blue Devil																								
Euchiton sp.	A Cudweed																								
Euchiton gymnocephalus	A Cudweed																								
Euchiton sphaericus	A Cudweed																								
Geranium sp.	Cranesbill	r																							
Glycine tabacina[2]	Vanilla Glycine																								
Gonocarpus tetragynus[1]	Raspwort																								
Goodenia pinnatifida[2]	Scrambled Eggs	1									r	1				+				2	r				
Hypericum gramineum[2]	Small St John's Wort																								
Juncus sp.	A Rush																								
Lomandra bracteata[1]	A Matrush																								
Lomandra filiformis[1]	A Matrush				+		+			r	r					r									
Lomandra multiflora[2]	A Matrush																								
Lomandra sp.[1]	A Matrush																								
Microtis unifolia[2]	Common Onion Orchid															r									
Ophioglossum lusitanicum	Adder's Tongue																						1		
Oxalis perennans	Soursob	r	r	+				r	r				r												4
Pimelea curviflora[2]	Curved Rice-flower																								

Scientific name	Common name	Quadrat number																							
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Plantago varia[2]	Variable Plantain																								
Ranunculus sp.	Buttercup	r																							
Rumex brownii	Swamp Dock																								
Schoenus apogon	Bog-rush																								
Sebaea ovata[2]																									
Senecio quadridentatus	Cotton Fireweed																								
Solenogyne dominii	Smooth Solenogyne																								
Stackhousia monogyna[2]	Creamy Candles																								
Tricoryne elatior[2]	Yellow Rush Lily					r														5					
Triptilodiscus pygmaeus[2]	Austral Sunray														r	+									
Vittadinia muelleri	Fuzzweed																								
Wahlenbergia sp.	A Bluebell		+		1				r			+													
Wahlenbergia communis	Tufted Bluebell						+			+															
Wahlenbergia luteola	A Bluebell															+	1			+					
Wahlenbergia stricta	Tall Bluebell																								
Wurmbea dioica[2]	Early Nancy																								
Xerochrysum viscosum[2]	Sticky Everlasting																								
Exotic grasses																									
Aira sp.	A Hairgrass	r	r		+	1	r	r	r	1	r	1		+	1	r	1	r	r	5	1	1	r	+	
Aira elegantissima	A Hairgrass																								+
Avena sp.	Wild Oats			r		r		+					r									r	r		
Avena barbata	Bearded Oats																								
Briza maxima	Blowfly Grass	2		+	1		r	1	5	2	1	1	1	2	1	+	1	3	1	5	2	1	1		
Briza minor	Shivery Grass		1										+				r	+		5		r		1	
Bromus sp.	A Brome Grass																								
Bromus catharticus	A Brome Grass																								
Bromus diandrus	A Brome Grass																								
Bromus hordeaceus	A Brome Grass																								r
Bromus mollis	Soft Brome																								
Cynodon dactylon	Couch																1								
Dactylis glomerata	Cocksfoot	4	r			r				1		3	2						2		r	1		4	

Scientific name	Common name	Quadrat number																							
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Eleusine tristachya	Goose Grass																								
Eragrostis curvula	African Lovegrass																								
Festuca sp.	A Fine-leaved Fescue																								
Festuca arundinacea	Tall Fescue																				r				
Lolium perenne	Perennial Ryegrass																								
Lolium rigidum	Ryegrass																								
Nassella neesiana	Chilean Needlegrass			+						1								r	r				r		
Nassella trichotoma	Serrated Tussock																								
Paspalum dilatatum	Paspalum	3																							
Phalaris aquatica	Phalaris			1																					
Poa bulbosa	Bulbous bluegrass																								
Rostraria cristata	Annual Cat's Tail																								
Vulpia sp.	Rat's-tail Fescue	1	r	1	+	1	+		5	1	r	1		1	+	+	1	+		5	1		1	1	r
Exotic forbs																									
Acetosella vulgaris	Sorrel																								
Anagallis arvensis	Scarlet Pimpernel																								
Arctotheca calendula	Capeweed																								
Bartsia sp.																		r							
Centaurium erythraea	Pink Stars																								
Centaurium tenuiflorum	Branched Centaury					+		+	r	1	+		+	+	+	+	+				r				
Cerastium glomeratum	Chickweed																								
Chondrilla juncea	Skeleton Weed						r																		
Cirsium vulgare	Spear Thistle																								
Conyza bonariensis	Flax-leaf Fleabane																								
Echium plantagineum	Paterson's Curse																								
Erodium cicutarium	Common Crowfoot																								
Galium divaricatum	A Bedstraw																								
Gamochaeta purpurea	A Cudweed																								
Gnaphalium sp.	A Cudweed																								
Hirschfeldia incana	Hoary Mustard																								
Hypericum perforatum	St John's Wort	r		+				+		+	1	2					+		+	5					

Scientific name	Common name	Quadrat number																							
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Hypochaeris glabra	Smooth Catsear	1	1	1		1	1	2		+		r	1		+	1	+	+		r		1	r		
Hypochaeris radicata	Catsear		3		+	1	3	r								2	+							r	+
Lactuca serriola	Prickly Lettuce																								r
Lepidium africanum	A Peppercress																								
Parentucellia latifolia	Common Bartsia																								
Petrorhagia nantueilii	Proliferous Pink																r								
Plantago lanceolata	Ribwort Plantain	2		1	r	r			r	r			+	1			r	r	+	5		1	+		
Romulea rosea	Onion Grass																								
Salvia verbenaca	Wild Sage																								
Silene gallica	French Catchfly																								
Sonchus oleraceus	Common Sow-thistle							+													r			r	
Tragopogon dubius																								1	
Tragopogon porrifolius	Salsify																								
Trifolium angustifolium	Narrow leaf Clover			r					4	3								2	2				1		
Trifolium arvense	Haresfoot Clover	1																							
Trifolium campestre	Hop Clover		+	1					r	+							+	3	r		r	+	+		3
Trifolium dubium								+																	
Trifolium glomeratum	Clustered Clover																								
Trifolium striatum																									
Trifolium spp.	Clovers																								

Appendix F Vegetation Survey 2016 – Floristic Value Scores

Indicator	Quadrat number																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Number of Common Species	5	5	4	3	6	5	5	6	6	3	5	4	4	4	4	7	4	3	7	4	0	4	1	1
Number of indicator level 1 species	1	0	1	1	1	2	0	0	1	2	1	1	0	1	2	0	0	0	0	0	0	1	0	0
Number of indicator level 2 species	1	0	0	1	1	1	0	0	0	2	2	0	0	2	4	0	0	0	2	2	2	1	0	0
Total number of native species	7	5	5	5	8	8	5	6	7	7	8	5	4	7	10	7	4	3	9	6	2	6	1	1
Number of exotic species	9	7	10	7	9	6	8	7	11	5	6	6	5	5	6	10	10	9	7	8	8	9	7	6
Number of significant weed species	1	0	2	1	0	0	1	0	2	1	1	0	0	0	0	1	1	2	1	0	0	1	0	0
Site value score	4	0	1	2	4	5	0	0	0	5	7	1	0	5	11	0	0	0	6	4	0	4	0	0

Appendix G Daily Minimum and Maximum Soil Temperatures

	1a		1b		2a		2b	
	Min (°C)	Max (°C)	Min (°C)	Max (°C)	Min (°C)	Max (°C)	Min (°C)	Max (°C)
15/06/2016	5.3	8.5	6.6	21.8	7.5	22.2	7.2	22.0
16/06/2016	3.7	8.5	5.1	9.6	5.7	10.3	5.5	10.0
17/06/2016	6.7	10.4	7.8	10.9	8.4	11.1	8.2	10.9
18/06/2016	9.4	12.0	9.9	12.0	10.2	12.5	10.2	12.3
19/06/2016	10.1	11.4	10.4	11.6	10.8	11.9	10.8	11.8
20/06/2016	10.6	13.5	10.7	13.3	11.0	13.4	11.0	13.3
21/06/2016	9.7	10.8	10.1	11.1	10.4	11.3	10.3	11.4
22/06/2016	9.2	10.7	9.6	11.2	9.9	11.7	9.9	11.6
23/06/2016	8.5	10.9	9.1	11.2	9.5	11.7	9.5	11.5
24/06/2016	6.9	10.2	7.6	10.7	8.2	11.2	8.2	11.0
25/06/2016	4.7	8.3	5.9	9.4	6.2	10.3	6.2	10.0
26/06/2016	3.4	7.1	4.8	8.0	5.3	8.3	5.2	8.0
27/06/2016	5.3	8.1	6.3	9.1	6.9	10.1	6.8	9.8
28/06/2016	3.5	7.5	4.6	8.6	5.2	9.8	5.1	9.4
29/06/2016	3.1	7.2	4.4	8.5	5.0	9.6	4.8	9.1
30/06/2016	3.1	6.7	4.1	7.4	5.0	7.8	4.7	7.5
1/07/2016	5.1	8.5	6.0	9.3	6.3	10.1	6.2	9.9
2/07/2016	3.3	7.6	4.5	8.7	4.9	9.5	4.9	9.2
3/07/2016	2.8	7.0	4.0	8.4	4.5	9.2	4.4	8.9
4/07/2016	3.8	7.3	5.0	8.3	5.7	8.8	5.6	8.5
5/07/2016	4.9	7.2	5.8	7.7	6.4	8.1	6.3	7.9
6/07/2016	6.1	8.7	6.7	9.1	7.1	9.4	7.0	9.2

7/07/2016	7.3	10.7	7.6	10.9	8.0	11.1	7.9	11.0
8/07/2016	6.8	10.2	7.2	10.3	7.6	10.5	7.6	10.3
9/07/2016	7.9	11.2	8.2	11.4	8.4	11.5	8.5	11.4
10/07/2016	7.6	11.8	8.1	11.7	8.5	11.9	8.6	11.7
11/07/2016	8.7	10.7	9.3	11.2	9.7	11.5	9.7	11.4
12/07/2016	7.2	10.2	7.7	10.6	8.3	10.9	8.2	10.7
13/07/2016	5.1	8.2	6.2	9.4	6.9	10.0	6.8	9.6
14/07/2016	3.8	7.8	5.2	9.3	5.6	9.8	5.5	9.4
15/07/2016	3.0	7.8	4.3	9.3	4.8	9.7	4.6	9.3
16/07/2016	3.3	8.6	4.7	10.0	5.0	10.3	4.8	9.9
17/07/2016	5.1	9.8	6.3	11.2	6.7	11.4	6.6	11.1
18/07/2016	4.5	10.6	5.9	11.1	6.1	11.1	6.1	11.0
19/07/2016	9.9	13.6	10.2	13.9	10.4	13.8	10.4	13.7
20/07/2016	10.7	13.0	10.8	13.0	11.0	13.2	11.2	13.1
21/07/2016	10.4	13.3	10.6	13.2	10.8	13.3	11.0	13.2
22/07/2016	10.7	13.7	10.8	13.4	11.0	13.4	11.2	13.4
23/07/2016	7.6	10.9	8.5	11.5	9.1	11.8	9.0	11.6
24/07/2016	5.4	8.6	6.7	9.3	6.9	9.5	6.9	9.3
25/07/2016	6.4	10.4	7.2	11.1	7.5	11.1	7.4	10.8
26/07/2016	6.7	9.9	7.4	11.2	7.5	11.1	7.5	10.9
27/07/2016	7.0	10.1	7.7	11.4	8.0	11.5	8.0	11.3
28/07/2016	5.7	10.3	6.9	11.7	7.0	11.5	7.0	11.3
29/07/2016	4.4	9.7	5.7	11.2	5.8	11.0	5.8	10.7
30/07/2016	5.9	9.1	6.9	10.8	7.2	10.8	7.2	10.5
31/07/2016	6.4	12.1	7.6	12.6	7.7	12.4	7.8	12.2
1/08/2016	7.8	11.3	8.5	11.4	8.8	11.4	8.8	11.3
2/08/2016	7.2	10.1	7.8	10.4	8.2	10.6	8.3	10.5

3/08/2016	5.7	10.8	6.6	11.9	6.7	11.6	6.8	11.5
4/08/2016	5.8	11.0	6.9	11.4	6.9	11.3	6.9	11.2
5/08/2016	6.0	11.7	6.8	12.5	7.0	12.3	7.1	12.1
6/08/2016	5.9	10.7	6.9	11.0	7.1	10.9	7.1	10.8
7/08/2016	7.1	10.8	7.7	10.9	7.9	11.0	8.0	10.8
8/08/2016	5.8	11.7	6.6	12.4	6.5	12.1	6.7	12.0
9/08/2016	6.0	11.7	6.9	12.4	6.9	12.2	7.0	12.0
10/08/2016	7.8	13.0	8.5	13.7	8.6	13.4	8.7	13.3
11/08/2016	7.4	12.5	8.3	13.2	8.2	12.8	8.4	12.8
12/08/2016	5.3	11.0	6.3	11.4	6.4	11.4	6.5	11.2
13/08/2016	5.9	11.6	6.8	12.7	7.0	12.3	7.1	12.3
14/08/2016	6.0	12.7	7.0	13.3	6.9	13.1	7.0	12.9
15/08/2016	5.7	12.6	6.7	13.2	6.6	13.0	6.7	12.8
16/08/2016	5.9	12.9	6.8	13.6	6.8	13.2	6.9	13.0
17/08/2016	7.1	11.6	7.9	11.9	8.1	11.8	8.1	11.7
18/08/2016	6.3	13.9	6.9	13.9	6.9	13.5	7.1	13.4
19/08/2016	6.9	13.6	7.3	13.6	7.4	13.3	7.6	13.2
20/08/2016	8.2	12.1	8.7	12.4	8.7	12.5	8.9	12.3
21/08/2016	7.3	10.9	8.0	11.4	8.3	11.4	8.4	11.3
22/08/2016	6.9	12.3	7.5	12.4	7.8	12.7	7.9	12.4
23/08/2016	8.6	13.2	9.2	13.0	9.0	13.1	9.2	13.0
24/08/2016	9.2	11.8	9.5	11.7	9.7	12.0	10.0	11.9
25/08/2016	7.6	14.2	8.1	14.1	7.9	13.9	8.1	13.8
26/08/2016	6.8	13.5	7.2	13.5	7.3	13.4	7.5	13.4
27/08/2016	6.1	13.2	6.8	13.3	7.1	13.2	7.3	13.1
28/08/2016	7.1	11.4	7.8	11.5	8.1	11.6	8.2	11.5
29/08/2016	6.5	13.5	7.0	13.0	7.2	13.0	7.4	12.9

30/08/2016	8.5	15.2	8.6	14.9	8.8	14.6	9.0	14.6
31/08/2016	11.1	14.5	11.2	14.3	11.5	14.2	11.7	14.3
1/09/2016	9.3	15.9	9.5	15.3	9.7	15.1	9.9	15.2
2/09/2016	10.7	12.1	10.7	12.1	10.9	12.1	11.1	12.2
3/09/2016	10.4	13.8	10.6	13.3	10.9	13.4	11.0	13.5
4/09/2016	9.2	16.1	9.6	15.3	9.7	15.2	9.8	15.2
5/09/2016	10.1	16.5	10.2	15.8	10.5	15.9	10.6	15.8
6/09/2016	9.2	17.5	9.3	16.5	9.6	16.3	9.7	16.4
7/09/2016	10.1	16.1	10.1	15.4	10.3	15.5	10.4	15.4
8/09/2016	11.8	18.0	11.7	17.1	11.8	16.9	12.0	16.9
9/09/2016	11.5	14.4	11.3	14.0	11.4	14.0	11.7	14.1
10/09/2016	12.3	15.2	12.3	14.7	12.5	14.7	12.7	14.7
11/09/2016	10.6	17.4	10.7	16.5	11.0	16.6	11.1	16.4
12/09/2016	10.0	18.4	10.2	17.1	10.2	17.1	10.5	17.1
13/09/2016	11.8	16.1	11.7	15.3	11.8	15.5	12.1	15.3
14/09/2016	12.0	15.7	12.0	15.3	12.1	15.2	12.4	15.2
15/09/2016	10.7	14.8	10.9	14.3	11.1	14.4	11.2	14.1
16/09/2016	10.7	16.1	10.8	15.7	11.0	15.7	11.2	15.8
17/09/2016	9.6	17.4	9.8	16.4	10.2	16.4	10.5	16.3
18/09/2016	11.4	14.1	11.3	13.8	11.5	13.9	11.8	13.9
19/09/2016	11.1	18.7	11.2	17.3	11.4	17.5	11.5	17.3
20/09/2016	10.2	16.7	10.2	15.9	10.5	15.9	10.8	15.7
21/09/2016	11.2	13.4	11.5	13.1	11.7	13.3	11.8	13.4
22/09/2016	11.0	14.8	11.3	14.4	11.4	14.5	11.5	14.5
23/09/2016	10.6	19.1	10.7	18.0	10.9	18.0	11.2	18.2
24/09/2016	11.4	19.6	11.3	18.2	11.5	18.1	11.9	18.1
25/09/2016	13.8	19.5	13.4	18.6	13.5	18.6	13.9	18.8

26/09/2016	11.3	19.8	11.2	18.6	11.6	18.6	12.1	18.8
27/09/2016	12.0	18.3	12.0	17.7	12.3	18.0	12.7	18.2
28/09/2016	10.1	20.2	10.4	18.6	10.8	18.8	11.3	18.9
29/09/2016	11.6	17.0	11.9	15.7	12.4	15.9	12.8	16.1
30/09/2016	10.5	16.7	11.0	15.2	11.4	15.4	11.6	15.5
1/10/2016	11.4	16.9	11.6	16.1	11.9	15.8	12.1	16.0
2/10/2016	11.1	20.8	11.0	19.0	11.3	19.1	11.7	19.5
3/10/2016	13.2	18.9	12.9	17.8	13.6	18.2	14.0	18.7
4/10/2016	11.5	16.8	11.6	16.1	12.2	16.5	12.6	16.8
5/10/2016	9.5	17.3	10.0	16.4	10.4	16.6	10.7	17.1
6/10/2016	11.6	20.1	11.6	18.9	12.1	19.2	12.6	19.7
7/10/2016	13.4	18.9	13.2	18.0	13.6	18.1	14.1	18.5
8/10/2016	13.4	20.3	13.0	19.1	13.4	19.4	13.9	19.4
9/10/2016	12.2	17.3	11.9	16.6	12.3	16.5	12.8	16.8
10/10/2016	12.6	16.2	12.5	15.7	12.8	15.9	13.3	16.2
11/10/2016	10.6	19.7	10.7	18.5	11.1	18.8	11.6	19.3
12/10/2016	10.5	17.9	10.5	17.1	11.1	17.4	11.5	17.8
13/10/2016	11.2	21.1	11.3	19.6	11.8	20.0	12.4	20.3
14/10/2016	11.4	22.4	11.2	20.6	11.6	20.8	12.1	21.0
15/10/2016	12.4	23.4	11.8	21.3	12.2	21.5	12.6	21.9
16/10/2016	14.0	23.3	13.4	21.6	13.7	21.5	14.1	22.1
17/10/2016	14.9	21.3	14.6	20.1	15.0	20.5	15.7	21.0
18/10/2016	12.9	20.7	12.6	19.6	13.0	19.8	13.7	20.7
19/10/2016	12.6	22.8	12.3	21.0	12.7	21.2	13.6	21.7
20/10/2016	13.1	22.3	12.5	20.7	12.8	21.1	13.4	21.1
21/10/2016	13.1	22.3	12.4	20.5	12.8	20.7	13.1	20.9
22/10/2016	14.1	19.9	13.6	18.9	13.8	18.6	14.5	19.2

23/10/2016	12.0	18.7	11.6	17.8	11.9	17.8	12.6	18.2
24/10/2016	11.3	22.8	11.0	21.1	11.2	21.3	11.8	21.2
25/10/2016	13.1	23.2	12.5	21.4	12.8	21.6	13.2	21.7
26/10/2016	15.4	25.5	14.7	23.3	14.9	23.6	15.3	23.6
27/10/2016	16.3	27.4	15.4	25.0	15.7	25.3	16.1	25.3
28/10/2016	17.2	21.1	16.2	19.9	16.6	20.1	17.0	20.0
29/10/2016	17.0	23.1	16.3	21.9	16.6	22.0	16.8	21.7
30/10/2016	17.2	22.0	16.5	20.9	16.7	20.8	16.9	21.1
31/10/2016	14.4	25.1	14.0	23.0	14.4	23.6	15.0	23.7
1/11/2016	13.3	23.9	12.5	22.0	13.2	22.6	13.5	22.5
2/11/2016	13.5	26.4	12.7	24.1	13.4	24.5	13.8	24.6
3/11/2016	15.1	27.9	14.0	25.6	14.8	25.8	15.1	25.9
4/11/2016	16.2	29.1	15.0	26.6	15.6	27.0	15.9	26.9
5/11/2016	17.7	28.6	16.6	26.2	17.3	26.9	17.6	26.8
6/11/2016	16.8	29.3	15.5	26.6	16.5	26.9	16.8	27.1
7/11/2016	17.7	30.5	16.2	27.9	17.2	27.9	17.5	28.1
8/11/2016	18.8	26.6	17.2	24.8	18.1	24.8	18.4	25.0
9/11/2016	19.5	27.5	18.4	25.7	19.0	25.8	19.3	25.7
10/11/2016	19.1	29.4	18.3	27.1	18.7	27.4	18.9	27.8
11/11/2016	18.9	30.1	18.1	27.7	18.6	28.3	18.9	28.1
12/11/2016	19.7	28.8	19.2	26.5	19.1	26.9	19.7	27.2
13/11/2016	18.5	25.7	17.8	23.7	18.4	24.3	18.9	24.8
14/11/2016	17.6	23.0	16.9	21.8	17.4	22.0	18.0	22.3
15/11/2016	16.1	25.8	15.6	24.1	16.0	24.1	16.6	24.4
16/11/2016	17.1	28.1	16.3	25.9	16.6	26.3	17.2	26.2
17/11/2016	19.7	29.7	19.0	27.3	19.2	27.8	19.7	27.7
18/11/2016	19.7	30.5	18.7	28.4	19.0	28.1	19.3	28.3

19/11/2016	21.2	32.1	20.1	29.8	20.3	29.6	20.7	29.5
20/11/2016	22.3	31.6	21.0	29.3	21.3	29.1	21.6	29.2
21/11/2016	22.4	32.5	21.3	30.0	21.5	29.7	21.9	30.2
22/11/2016	21.9	32.6	20.8	29.9	21.1	30.1	21.6	30.3
23/11/2016	19.3	23.4	18.8	22.3	19.2	22.6	19.7	22.9
24/11/2016	16.2	27.7	15.8	25.7	16.4	25.7	16.8	26.2
25/11/2016	17.2	30.2	16.4	27.3	17.0	27.6	17.5	27.7
26/11/2016	19.9	31.5	18.7	28.6	19.2	28.8	19.6	28.8
27/11/2016	20.7	32.8	19.3	30.0	19.7	30.1	20.1	29.7
28/11/2016	23.1	34.6	21.6	31.6	22.0	31.5	22.2	31.6
29/11/2016	21.7	32.6	19.9	30.0	20.6	29.6	20.8	30.1
30/11/2016	22.8	33.8	21.2	31.2	21.7	30.9	22.2	31.2
1/12/2016	23.5	35.8	21.8	32.7	22.3	32.6	22.8	32.9
2/12/2016	22.8	34.8	20.9	32.0	21.6	32.1	22.2	32.2
3/12/2016	24.2	35.9	22.4	33.1	23.1	33.0	23.6	33.0
4/12/2016	24.2	34.5	22.4	32.0	23.0	31.6	23.5	31.8
5/12/2016	25.5	30.4	23.9	28.7	24.3	28.6	24.8	28.7
6/12/2016	22.6	26.4	21.7	25.4	22.0	25.4	22.5	25.7
7/12/2016	19.6	31.7	18.9	29.4	19.4	29.8	19.9	29.8
8/12/2016	20.4	32.1	19.4	29.4	19.9	29.9	20.3	30.2
9/12/2016	20.0	31.7	19.0	28.9	19.6	29.3	20.4	29.8
10/12/2016	20.3	33.4	19.1	30.7	19.7	30.7	20.4	30.8
11/12/2016	22.6	35.1	21.2	32.5	21.5	32.2	22.1	32.0
12/12/2016	24.6	37.0	23.2	34.2	23.4	33.8	23.9	33.9
13/12/2016	24.1	34.2	22.3	31.8	22.8	31.2	23.3	31.8
14/12/2016	24.3	28.2	23.1	26.5	23.4	26.5	24.0	27.1
15/12/2016	20.2	23.3	19.6	22.2	20.0	22.6	20.6	23.2

16/12/2016	19.2	22.2	18.7	21.7	19.1	21.7	19.7	22.0
17/12/2016	20.0	27.9	19.6	26.4	19.9	26.6	20.2	27.3
18/12/2016	19.6	31.1	19.0	28.6	19.7	29.4	20.0	29.1
19/12/2016	20.6	31.6	19.8	29.5	20.4	29.7	20.7	29.7
20/12/2016	20.9	30.3	19.7	28.2	20.4	28.0	20.5	28.8
21/12/2016	20.9	34.5	19.6	31.7	20.3	31.3	20.5	31.8
22/12/2016	24.2	35.0	22.7	32.5	23.0	32.1	23.3	32.2
23/12/2016	24.9	37.0	23.5	34.5	23.8	33.6	24.1	33.9
24/12/2016	24.8	36.9	23.5	34.5	23.7	33.5	24.1	33.9
25/12/2016	22.1	33.4	21.0	31.0	21.3	31.1	21.7	31.4
26/12/2016	23.4	33.5	22.4	31.2	22.7	31.3	23.1	31.7
27/12/2016	24.8	30.8	23.7	29.3	24.1	29.1	24.4	29.4
28/12/2016	23.9	30.4	22.9	28.8	23.2	28.4	23.5	29.0
29/12/2016	25.2	29.4	24.1	28.1	24.3	27.8	24.7	28.2
30/12/2016	24.4	31.9	23.6	30.3	23.9	30.1	24.2	30.4
31/12/2016	23.4	35.4	22.6	32.8	23.0	33.0	23.4	33.5
1/01/2017	23.6	28.7	22.4	27.4	22.9	27.3	23.5	27.7
2/01/2017	22.6	33.2	21.7	31.3	22.1	30.6	22.7	31.0
3/01/2017	23.9	35.9	22.8	33.4	23.0	32.5	23.5	33.1
4/01/2017	24.2	31.3	23.0	29.6	23.2	29.5	23.8	29.3
5/01/2017	23.3	36.1	22.3	33.9	22.6	32.6	23.0	33.1
6/01/2017	24.5	37.3	23.2	34.7	23.5	33.4	24.1	34.0
7/01/2017	25.3	38.1	23.9	35.4	24.2	34.0	24.7	34.7
8/01/2017	26.5	35.1	25.0	33.1	25.3	32.0	25.7	32.6
9/01/2017	27.3	35.2	25.9	33.2	26.1	32.3	26.5	32.8
10/01/2017	25.8	35.7	24.6	33.5	25.0	32.5	25.4	33.1
11/01/2017	26.5	39.6	25.2	36.7	25.5	35.6	25.9	36.3

12/01/2017	26.5	40.3	24.9	37.3	25.4	36.1	25.8	36.5
13/01/2017	28.9	36.9	27.4	34.5	27.8	33.8	27.9	34.2
14/01/2017	26.5	38.7	25.5	35.8	25.9	34.4	26.4	35.3
15/01/2017	25.0	39.2	23.6	36.0	24.1	34.9	24.5	35.3
16/01/2017	27.5	41.1	26.1	37.9	26.5	36.7	26.7	37.2
17/01/2017	27.2	41.5	25.7	38.3	26.2	37.0	26.4	37.6
18/01/2017	28.6	39.4	26.9	36.6	27.4	35.7	27.7	36.5
19/01/2017	27.7	32.9	26.3	31.0	26.8	31.7	27.1	30.7
20/01/2017	24.4	30.3	23.6	29.0	24.1	29.6	24.5	28.9
21/01/2017	20.6	35.4	20.0	32.4	20.6	32.2	21.2	32.3
22/01/2017	24.1	38.0	23.2	35.2	23.6	34.2	24.0	34.4
23/01/2017	25.6	38.1	24.4	35.3	24.6	34.2	24.9	34.5
24/01/2017	27.5	34.1	26.1	32.5	26.5	31.1	26.9	32.2
25/01/2017	24.8	32.8	23.8	30.8	24.1	30.4	24.7	30.4
26/01/2017	24.3	38.4	23.4	35.7	23.8	34.5	24.2	34.7
27/01/2017	26.3	39.1	25.1	36.4	25.4	35.0	25.6	35.3
28/01/2017	26.9	40.1	25.6	37.2	26.0	35.7	26.0	36.2
29/01/2017	26.6	41.0	25.2	37.8	25.7	36.3	25.8	36.7
30/01/2017	28.0	40.4	26.5	37.3	27.0	36.1	27.0	36.7
31/01/2017	29.4	38.8	27.8	36.2	28.2	35.4	28.3	35.7
1/02/2017	24.7	29.8	23.8	28.4	24.5	28.6	24.8	28.8
2/02/2017	22.5	33.1	21.9	31.1	22.5	30.4	22.9	30.8
3/02/2017	23.7	36.3	23.0	33.9	23.3	32.7	23.8	33.2
4/02/2017	24.5	35.1	23.4	32.9	23.7	31.8	24.1	32.1
5/02/2017	25.3	37.5	24.1	35.0	24.5	33.9	24.7	34.2
6/02/2017	27.3	34.1	26.2	32.3	26.3	31.8	26.6	31.9
7/02/2017	23.6	27.5	23.0	26.5	23.3	26.7	23.9	26.9

8/02/2017	22.5	26.8	22.1	26.0	22.3	25.9	23.0	26.1
9/02/2017	23.3	35.2	22.9	33.7	23.1	33.0	23.5	32.9
10/02/2017	26.1	38.6	25.1	36.7	25.2	35.4	25.5	35.8
11/02/2017	28.2	39.4	26.9	37.3	27.1	35.8	27.3	36.6
12/02/2017	24.0	33.1	23.1	32.6	23.3	31.1	24.2	32.3
13/02/2017	21.1	34.6	20.3	32.4	20.6	31.0	21.6	32.3
14/02/2017	24.5	37.0	23.5	34.4	23.5	33.2	24.1	34.1
15/02/2017	25.3	37.0	24.0	34.8	24.1	33.3	24.8	34.3
16/02/2017	25.0	38.1	23.6	35.8	24.0	34.3	24.3	35.2
17/02/2017	25.4	37.5	23.9	35.4	24.3	33.9	24.6	34.9
18/02/2017	22.7	28.3	21.7	27.2	22.2	26.9	22.5	27.5
19/02/2017	19.6	31.6	18.7	30.0	19.2	28.5	19.7	29.7
20/02/2017	20.0	31.8	19.2	30.3	19.4	28.8	20.1	30.1
21/02/2017	19.7	33.4	18.7	31.5	19.1	30.1	19.7	31.1
22/02/2017	22.8	35.8	21.7	33.7	21.9	32.1	22.2	32.9
23/02/2017	24.1	36.8	22.8	34.6	23.1	32.8	23.3	33.8
24/02/2017	25.1	37.3	23.6	34.7	23.9	33.5	24.1	34.3
25/02/2017	25.7	29.6	24.6	28.1	25.0	28.4	25.3	28.4
26/02/2017	23.4	34.8	22.4	32.5	22.8	31.6	23.3	32.4
27/02/2017	23.6	33.4	22.4	31.2	22.8	31.0	23.2	31.1
28/02/2017	23.6	31.7	22.6	29.9	23.0	29.6	23.3	30.0
1/03/2017	22.3	33.3	21.3	31.3	21.7	30.5	22.1	31.0
2/03/2017	24.0	31.0	23.0	29.8	23.4	29.2	23.6	29.5
3/03/2017	23.4	32.0	22.6	30.4	22.9	29.9	23.3	30.4
4/03/2017	22.7	27.5	22.1	26.4	22.6	26.6	22.8	27.0
5/03/2017	20.7	29.4	20.3	28.3	20.7	27.9	21.0	29.0
6/03/2017	19.3	29.6	19.1	28.6	19.5	27.6	20.0	29.3

7/03/2017	19.9	30.3	19.6	28.7	20.0	28.0	20.5	29.1
8/03/2017	20.8	27.2	20.3	26.1	20.6	25.9	21.1	26.4
9/03/2017	20.3	30.8	19.9	29.2	20.2	28.3	20.6	29.1
10/03/2017	20.0	31.8	19.2	30.2	19.6	28.6	20.1	29.8
11/03/2017	21.8	30.6	21.0	29.3	21.2	28.1	21.7	28.9
12/03/2017	21.9	32.4	21.1	31.0	21.1	29.2	21.6	30.3
13/03/2017	23.3	28.6	22.5	27.1	22.5	26.7	23.1	27.4
14/03/2017	21.2	25.4	20.6	24.3	20.7	24.3	21.3	24.7
15/03/2017	21.1	25.6	20.7	24.5	20.9	24.7	21.1	25.2
16/03/2017	21.7	26.6	21.4	25.9	21.4	25.8	21.8	26.3
17/03/2017	20.9	27.7	20.5	26.8	20.6	26.6	20.8	27.5
18/03/2017	20.0	25.4	19.7	24.7	20.1	25.1	20.4	25.5
19/03/2017	21.1	25.8	20.8	25.1	21.1	25.4	21.4	25.7
20/03/2017	21.4	29.6	21.1	28.7	21.2	28.3	21.5	29.0
21/03/2017	22.2	24.4	22.1	23.9	22.1	23.9	22.3	24.1
22/03/2017	21.2	25.8	21.0	25.6	20.9	24.6	21.1	25.5
23/03/2017	20.3	22.7	20.3	22.3	20.2	22.3	20.5	22.6
24/03/2017	19.6	23.3	19.6	22.7	19.6	22.8	19.8	23.1
25/03/2017	19.2	21.6	19.1	21.4	19.2	21.5	19.5	21.7
26/03/2017	17.6	25.9	17.7	25.2	17.7	24.5	17.9	25.4
27/03/2017	19.7	27.2	19.4	26.1	19.3	25.4	19.7	26.3
28/03/2017	21.3	27.8	20.8	26.6	20.7	26.1	21.2	26.9
29/03/2017	19.6	26.4	19.2	25.2	19.2	24.7	19.5	25.5
30/03/2017	18.5	23.1	18.3	22.5	18.4	22.4	18.7	22.8
31/03/2017	16.1	23.1	16.3	22.3	16.1	21.9	16.5	22.8
1/04/2017	16.3	23.3	16.2	22.2	16.1	22.0	16.5	22.7
2/04/2017	17.7	22.6	17.4	21.8	17.5	21.6	18.0	22.3

3/04/2017	15.6	19.4	15.6	19.1	15.6	19.2	16.0	19.6
4/04/2017	14.7	19.7	14.8	19.4	15.0	19.4	15.3	19.8
5/04/2017	14.6	21.7	14.6	20.8	14.8	21.1	15.1	21.4
6/04/2017	15.3	22.3	15.1	21.4	15.3	21.3	15.7	21.9
7/04/2017	14.8	22.0	14.6	21.1	14.9	21.1	15.2	21.7
8/04/2017	15.2	21.6	14.9	20.9	15.2	20.7	15.5	21.2
9/04/2017	14.5	16.7	14.4	16.3	14.5	16.4	14.7	16.7
10/04/2017	13.7	17.6	13.7	17.3	13.8	17.4	14.0	17.7
11/04/2017	13.2	19.2	13.3	19.0	13.4	18.9	13.6	19.6
12/04/2017	14.0	19.7	14.0	19.3	14.0	19.2	14.4	19.8
13/04/2017	14.6	19.4	14.6	18.9	14.6	18.7	15.0	19.3
14/04/2017	13.5	19.7	13.5	19.4	13.4	19.1	13.8	19.8
15/04/2017	14.1	19.3	14.1	19.2	14.2	19.1	14.5	19.7
16/04/2017	12.9	18.7	13.0	18.2	13.1	18.2	13.4	18.8
17/04/2017	13.9	19.5	13.9	19.5	14.0	19.2	14.2	19.8
18/04/2017	15.3	20.7	15.3	20.5	15.3	20.5	15.6	21.0
19/04/2017	15.5	20.7	15.5	20.5	15.6	20.5	15.9	21.0
20/04/2017	15.0	20.2	15.1	20.3	15.1	20.1	15.3	20.7
21/04/2017	15.1	19.0	15.0	18.8	15.2	18.8	15.4	19.1
22/04/2017	16.2	19.2	16.2	19.5	16.2	19.4	16.5	19.7
23/04/2017	14.4	19.6	14.5	19.8	14.6	19.7	14.8	20.2
24/04/2017	15.4	19.8	15.4	19.7	15.6	19.8	15.8	20.1
25/04/2017	15.9	18.0	15.9	17.7	15.8	17.7	16.1	18.0
26/04/2017	13.6	16.4	13.7	16.4	13.8	16.4	14.1	16.7
27/04/2017	11.2	15.5	11.6	16.2	11.4	16.0	11.8	16.7
28/04/2017	10.3	15.1	10.7	15.8	10.7	15.7	11.1	16.2
29/04/2017	10.2	14.8	10.6	15.6	10.8	15.5	11.1	16.0

30/04/2017	10.9	15.8	11.4	16.7	11.6	16.5	11.8	17.0
1/05/2017	10.8	15.6	11.2	16.2	11.4	16.1	11.6	16.4

Appendix H Meteorological Data: Canberra Airport (2013-2016)

Year	Month	Monthly Precipitation (mm)	Average Maximum Daily Air Temperature (ºC)	Average Minimum Daily Air Temperature (ºC)	Average Maximum Daily Soil Temperature (ºC at 10 cm depth)	Average Minimum Daily Soil Temperature (ºC at 10 cm depth)
2013	January	72.6	32.3	13.9	33.2	23.8
2013	February	30.0	27.4	12.8	30.0	21.4
2013	March	197.2	25.7	9.6		
2013	April	9.8	22.1	5.5		
2013	May	19.8	17.4	1.3		
2013	June	85.2	13.9	1.6		
2013	July	42.8	13.4	1.7	10.5	6.2
2013	August	27.0	14.8	2.4	12.1	6.6
2013	September	91.0	19.9	4.0	17.8	10.8
2013	October	13.4	21.9	3.8	21.7	13.3
2013	November	105.6	23.8	6.7	25.3	16.3
2013	December	23.2	28.5	11.5	33.7	23.6
2014	January	4.8	31.6	12.1	35.7	24.8
2014	February	83.6	29.4	13.5	33.2	23.8
2014	March	88.0	24.2	12.2	25.0	18.7
2014	April	16.9	19.7	7.4	19.3	13.9
2014	May	14.4	17.6	2.7	14.7	9.5
2014	June	57.2	13.2	2.8	10.7	7.3
2014	July	34.9	12.2	0.0	9.1	4.9
2014	August	26.8	14.3	-0.8	11.8	5.7
2014	September	36.2	17.9	2.7	16.9	9.5
2014	October	53.4	22.5	5.4	22.5	13.9
2014	November	29.0	27.9	10.2	29.5	19.9
2014	December	102.0	27.7	12.7	29.5	20.4
2015	January	34.8	27.2	13.9	29.6	21.4
2015	February	30.2	28.3	13.0	30.0	21.4
2015	March	12.4	26.1	9.0	27.1	18.6
2015	April	91.8	19.1	7.1	17.7	12.6
2015	May	12.2	16.0	2.8	14.0	8.8
2015	June	55.2	13.7	-0.8	10.6	5.7
2015	July	37.2	11.6	-0.7	8.6	3.9
2015	August	66.8	13.7	1.0	10.7	5.3
2015	September	13.6	17.7	1.5	17.3	8.7
2015	October	26.6	24.8	8.3	24.6	16.2
2015	November	67.6	25.6	10.9	26.1	17.9
2015	December	34.8	29.3	11.4	32.3	21.9

Year	Month	Monthly Precipitation (mm)	Average Maximum Daily Air Temperature (ºC)	Average Minimum Daily Air Temperature (ºC)	Average Maximum Daily Soil Temperature (ºC at 10 cm depth)	Average Minimum Daily Soil Temperature (ºC at 10 cm depth)
2016	January	106.4	28.5	14	29.0	21.5
2016	February	23.4	29.3	13.3	31.5	22.6
2016	March	28.4	27.7	12.6	28.1	20.2
2016	April	6.8	23.8	8.3	22.8	16.3
2016	May	47.6	17.4	4.8	15.0	9.9
2016	June	144.2	13.0	3.0	10.4	6.6
2016	July	71.0	12.7	2.2	10.2	5.8
2016	August	46.2	14.3	1.1	11.9	5.8
2016	September	149.2	15.8	4.8	14.7	8.7
2016	October	43.6	18.5	5.2	19.5	11.0
2016	November	56.8	24.8	8.6	28.0	17.6
2016	December	64.6	28.7	13.5	29.8	21.4